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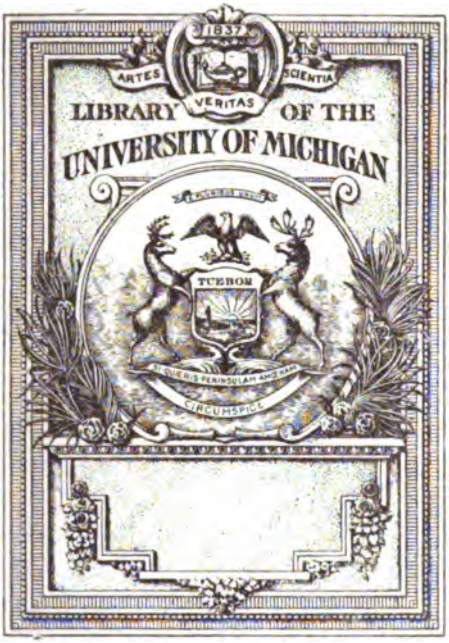
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MAJOR C. B. MAYNE, R.E.

ROYAL ENGINEERS INSTITUTE.

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PREFACE.

THE attention of the reader of Volume XXI. of the *Occasional Papers* for 1895 is especially directed to the very valuable lectures on *Railway Construction* delivered by Sir Guilford Molesworth, K.C.I.E., M.I.C.E., at the School of Military Engineering during the Autumn of 1894.

Major A. J. Hughes' paper on *Field Artillery and Okehampton Experiences* gives to the Military Engineer the results of certain English artillery experiences in 1893. Such information must always be welcome to Royal Engineer officers, from the fact that they cannot properly perform a considerable part of their duties unless they closely follow the progress being made in the construction, use, and effect of weapons employed for the destruction, in battle, of men and materials. The paper on *The Battle of Woerth* was written some years ago by the late Capt. R. da Costa Porter, R.E., and has very kindly been contributed by his widow. Like everything else that came from Capt. Porter's pen, his paper affords a very excellent illustration of the possible uses to which the handmaiden Engineer arm can be put during a battle. The tale is so graphically told that the reader is in danger of imagining that everything took place as is described in the paper. Consequently the reader's attention is called to Capt. Porter's own warning on the subject (see p. 43 and footnote). Major W. D. Conner in his paper on *Fortification in Savage Warfare* has collected a number of useful examples of the employment of defensive works in the savage wars undertaken by European nations. Naturally the majority of the cases are drawn

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from British experiences. The Editor has contributed the paper on *The Organization of the Military and Administrative Services during a Siege.* This subject has hardly been considered at all by English military writers, though the "principles" contained in it are applicable to the smallest defensive post. The latest *Tables of Service Ordnance*, corrected to March, 1895, are published with the kind permission of the War Office.

Major G. K. Scott-Moncrieff's paper on *The Design of Soldiers' Barracks* deals with a subject of the greatest importance, and offers suggestions which cannot but be useful to those who are interested in the design of the buildings in which the soldier has to spend his military career. The ever present question of how to dispose of the sewage of our houses and towns is discussed by Mr. Chas. H. Beloe, M.I.C.E., in his paper on *Sewage Purification* by the International Company Process. Major H. Appleton, R.E., has contributed a short but useful paper describing *The Olvusâa Suspension Bridge* erected across the Southern White River in Iceland. The special advantageous features of this bridge are noted in the paper.

Mr. A. A. C. Swinton's paper on *Electric Currents of High Pressure and Periodicity* deals with a subject, the utility of which is as yet unforeseen. The physical effects of such currents are extraordinary, but like so many other discoveries, time and the race for wealth will doubtless eventually find a place for this particular one to aid in the administration of the wants of society.

C. B. MAYNE, MAJOR, R.E.,
Secretary, R.E. Institute.

CHATHAM.
December 1*st*, 1895.

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PAPER I.

FIELD ARTILLERY AND OKEHAMPTON EXPERIENCES.

BY MAJOR A. J. HUGHES, R.A.

I.

THE paramount consideration for field artillery is good shooting at the right time and from the right place. It thus requires—

1. Mobility.
2. Power or fire effect.

I have placed mobility first because considerations of mobility really govern the power, since a gun, however powerful, can be of no use unless it can be brought into action at the correct time and place.

Mobility is a very large subject, but in this lecture I propose only to go into it sufficiently to explain the changes, chiefly those with reference to the ammunition supply, that have lately taken place before passing on to the consideration of power and effects.

The considerations which affect mobility are of two natures—

I. Administrative and tactical.
II. Technical.

The former includes—

1. Distribution of batteries and ammunition columns.
2. Position on the line of march.
3. Peace training.

The latter includes—

1. Weight behind team.
2. Method of draught employed.

DISTRIBUTION OF BATTERIES.

We and all foreign nations adopt the 6-gun battery as the fire unit. The Austrians and Russians, from motives of economy, have 8-gun field batteries; their horse batteries have, however, only six guns, as the 8-gun battery, owing to its being so large a command for one man, has not sufficient mobility.

The tactical unit is the brigade division, consisting usually of three batteries under a lieut.-colonel. The term brigade division is not a happy one, and various suggestions have been made for some simpler name; an artillery brigade seems the natural one.

The artillery of a division consists of one brigade division of three batteries; the corps artillery of three horse and two field. We thus have a total of 14 batteries to an army corps, the proportion of guns to men being 3·5 per 1,000—considerably less than foreign nations, the Germans and French having five, the Italians nearly four.

A cavalry division has two horse artillery batteries attached to it. These batteries work with the cavalry division, but in a general engagement would take their place in the general line of artillery. This necessity, apart from the complication of equipment, is the chief objection to arming the horse artillery batteries of the cavalry division with, as is often proposed, machine guns, since, if so armed, they would be comparatively useless during the artillery duel.

With regard to the ammunition, there are three sources of supply—

1. That with the guns.
2. The divisional reserve.
3. The ammunition park.

The supply with the guns consists of 108 rounds per gun—36 in the limber and 72 in the wagon. On the line of march each wagon follows its own gun; this is most important. Only a few years back all the wagons of a brigade division were placed together on the line of march in rear of the guns, consequently, when the artillery was ordered to the front, the guns trotted off, followed by a long line of wagons; the former were allowed to pass other troops all right, but directly the wagons appeared they were often stopped, and thus were cut off from their guns, and one could never tell when they would rejoin them. This might be very serious, as the ammunition in the limbers with rapid fire will only last about 40 minutes.

Prince Kraft, in one of his letters on artillery, thus relates an experience of his:—

"On the morning of the 3rd of July, 1866, as I was about to start, the commander of the 2nd Field Brigade came up to me with the request that I would allow him to march with all the guns of the batteries of his brigade at the head of the column, and would permit the whole of the wagons to follow in rear, saying that unless I permitted this he could not command his brigade as a whole in its advance against the enemy. Hurried as I was, I said as I rode off, 'All right; do as you like.' I bitterly repented this. For what happened?

"The orders given in Königinhof by the General commanding the corps directed that the reserve artillery should cross the Elbe at Königinhof after the 1st Division of the Guard, and should be followed by the 2nd Division of the Guard. After I had led the head of the reserve artillery into Königinhof, and begged the commander of the 2nd Division to allow them to go in front of him, I pushed on in order to make myself acquainted with the position of the battle. In the meanwhile, the 2nd Division of the Guard had allowed the batteries of the corps artillery to pass through the town. But when the division saw nothing but ammunition wagons following (there were 40 of them) they mistook them for an ammunition column, and burning for action, and not being willing to follow the 'train' in their advance against the enemy, marched off, forcing the wagons to make way for them, since orders had been given that the ammunition columns were not to cross the Elbe. In this manner the ammunition wagons of the batteries of the reserve artillery were missing during the whole of the battle, as they followed in rear of all, and had then to find their batteries on the field of battle, in which they did not succeed until the action was already over."

He then goes on to say that at 4.30 p.m., in consequence of many of the batteries having only two rounds left, he was forced to join in the retreat, and ends the account with the words, "But I learnt one lesson by this, 'never again to allow the batteries to be separated from all their wagons.'"

The 1st reserve of ammunition is called the divisional reserve, and consists of 39 carriages, 6 of which are ammunition wagons. It carries 74 rounds per gun. The corresponding reserve for the corps artillery is called the corps reserve, and carries a similar amount per gun for the batteries of the corps artillery. This reserve marches close in rear of the combatant troops. If more than one division is marching on one road the G.O.C. decides as to whether each marches in rear of its own division or in rear of the whole force. The 2nd reserve is called the ammunition park, and carries 72 rounds per gun. It is divided into four sections, told off respectively to the 1st, 2nd, and 3rd Divisions and the corps artillery. The 1st, 2nd, and 3rd sections consist of 26 carriages, the 4th of 22; they all march together, but each section is complete in itself, so that, should a division be detached, its section of the ammunition park can follow it. The artillery park marches, if possible, about a day's march in rear. The total rounds carried in the field are, therefore, 256, of which 108 are actually with the guns.

Most foreign nations carry considerably more rounds in the field, and have on an average 30 more *with the battery.*

In France and Germany there are 9 wagons with the battery, and in Russia 12; this latter shows the immense importance attributed by the nation which has been last in war—on a large scale—to a sufficient supply of ammunition. In weight of ammunition carried they also show a large superiority, their horse artillery shell averaging 15lbs. and their field 17lbs. against our 12½lbs.

In both these respects it is hoped we shall soon be better off, for the new horse artillery equipment is designed to carry 142 rounds per gun, and a new wagon, carrying 100 15lb. shell, for field batteries has been tried with success. This increase of rounds carried is in a great measure due to the saving in weight affected by the introduction of cordite. Thus the charge for the horse artillery gun is only 12ozs., and that for the regular 12-pounder 1lb., instead of 4lbs. black—a saving of nearly 1cwt. per limber.

POSITION ON THE LINE OF MARCH.

This has now to be as far forward as is consistent with safety. Artillery, owing to its long range, should be the first to come into action, to prepare the way for, and cover the deployment of its infantry. Formerly, guns were kept in reserve, and not launched into the fight until the decisive moment; once in action they were practically out of the commander's hands, and could not be moved. Nowadays ranges are so long that in the earlier stages of the fight it is easy to move batteries.

In 1866 the Prussians had not recognized this. In their columns the artillery was placed far to the rear, and seldom made its appearance until too late to be of much use. The Austrians, on the contrary, had theirs well to the front. Thus at the battle of Nachod the Austrians had 96 guns, the Prussians 90; of these, by 11 a.m., there were in action 12 Prussian against 32 Austrian; by noon, 18 Prussian against 32 Austrian; by 4.30 p.m., 18 Prussian to 80 Austrian. Subsequently the Prussian total was made up to 66.

After 1866 the Germans set to work to organize and train their artillery in accordance with the experience gained, and in 1870 we saw the result. Here the artillery is always well forward on the line of march, and deployed in full force at the commencement of the fight. At Worth the V. Corps (the same corps that was so slow at Nachod) was deployed before its infantry. Again, the XII. Corps, moving through the Forest of Beaumont, had the whole of its artillery close at the head of the main body—only one company of infantry in front. As a consequence, they were able to cover the deployment of the infantry from the wood.

PEACE TRAINING.

Every attempt is now made to make this as thorough a preparation for war as possible. Batteries are trained to move over long distances and at a rapid pace. For coming into action two well-defined systems—the direct and the deliberate—are laid down, the former for use when the range is short and target distinct, and the latter when the range is long and the battery can approach its firing position under cover.

The regulations for the ammunition supply are also very clearly defined. Thus at the commencement of an action the supply is always from the wagons, that in the limbers being kept intact as long as possible. Directly a battery moves into action the captain sends forward three wagons. These form up 4 yards in rear of their guns, and the teams unhook.

The captain forms up the other three wagons from 200 to 400 yards in rear; they are joined by the gun limbers and teams of the front wagons. About one mile in rear comes the divisional reserve, and a day's march in rear is the ammunition park.

The supply is what is called worked from the rear to the front, that is to say, the rear echelon has to keep touch with the one next in front of it, and the ammunition is to be offered and not called for.

WEIGHT BEHIND SPLINTER-BAR.

The weight behind the splinter-bar for horse artillery should not exceed 30cwt., and for field artillery about 37cwt.

At present our horse artillery is badly over-weighted, and even in peace-time, on really long hard days, is unable to keep up.

The new horse artillery equipment, a light 12-pounder having a velocity of 1,550 f.s., will greatly improve us in this respect, the weight of gun and limber being 30cwt. 3qrs., and that of wagon 30cwt. 1qr.

SYSTEM OF DRAUGHT.

Up to now we have been the sole possessors of shaft draught, and although many doubted the wisdom of it, it held its own, until the drill of wagon supply and consequent necessity of rapidly unhooking the teams brought the question to the front. For the last three years extensive trials have been carried on with various systems, and it has, I believe, been decided to introduce a modification of the Swiss system.

The advantages of pole draught are—

1. Horses all interchangeable, no special heavy horses being required for the off wheeler.
2. Fallen horses more easily disengaged.
3. More and better distributed power of holding back.
4. Freer movement of the wheel horses.

The disadvantages are—

1. Increased weight on the wheel horses' necks, liable to cause galls.
2. Not so handy for driving over rough ground.

The balance of advantage rests decidedly with the pole; in fact, it is a necessity now that the wagon horses are unhooked.

The five systems tried were two German, the Indian, American, and Swiss.

The first two have long poles with a hook at the end and swingle trees, to which the centre horses are attached; the last three have direct draught, as in the shaft system.

In the swingle tree system the weight of the pole is taken by the centre horses when the team is in draught, and it is only when the traces are slack that the weight comes on the necks of the wheelers. In the other systems the pole is shorter and lighter, but its weight is never off the wheel horses.

The one most liked was the Swiss, and the new horse artillery limbers are fitted with it. It consists of a pole of medium length supported by a wooden cross-bar buckled to the bottom of the wheelers' collars.

The pole chains are not attached to the collar, but connected by a strap directly with the breechings; the strain of stopping the carriages is thus taken entirely by the breechings. The trace draught is similar to that with shafts, except that those of the wheelers are hooked to swingle trees. To unhook, the pole chains have to be cast loose, and the wheelers' swingle trees unhooked. The horses can then move straight to the front.

All the horses carry breeching, and have exactly similar harness.

II.

POWER.

First, what is field artillery fire effect? It is most certainly man killing, and not the destruction of material or earthworks. It is of no use even attempting to silence artillery by the destruction of its guns and carriages. All war experience goes to prove this. Prince Kraft, talking of the battle of Könnigratz, says:—

"We captured nearly 200 guns; not one in the whole number, as far as I know, had been injured by fire. The reports of the victorious infantry declare that they, in general, captured only such guns as had lost their teams by fire."

Again, in 1870, in Von Dresky's account of Chilleurs aux Bois, we read:—

"As for the effect of our fire on that day, we found afterwards on passing the abandoned positions of the French a certain number of gunners and horses killed and wounded; not a gun was, however, put out of action."

Numberless similar instances could be quoted; it was the same throughout the war. Whilst as to the destruction of *personnel* we find whole batteries put out of action by the loss of nearly all their men and horses in the fighting line, and although replaced afterwards the loss is still a permanent one.

When high muzzle velocity was first introduced it was thought by many that it would enable field artillery to produce effects on material, and the 12-pounder was designed rather to fire a long common shell having a high velocity with great accuracy than with regard to its shrapnel effects. Experience soon showed that, notwithstanding high muzzle velocity, field artillery was still powerless to damage material. High explosives in field guns have also, up to now, proved useless in this respect. Great attention has, therefore, been lately paid to obtaining better results from shrapnel.

Simplicity in ammunition is rightly held to be such an advantage that everyone is striving to obtain a general utility shell, and of all the projectiles now in use shrapnel most nearly fulfils field artillery requirements, for it gives most fragments, covers the greatest depth, is efficient against troops in houses, and is fairly efficient for ranging purposes.

Let us now consider the ammunition, gun, and carriage, in order to see how to obtain the best results from the weight allowed by mobility.

AMMUNITION.*

The projectiles now in use are common, ring, case, shrapnel, and high explosive.

Common.—Of this we are the sole possessors. It is a tough steel shell containing a burster of 1lb. 8ozs. In consequence of its toughness, it only breaks into a few pieces; in fact, it does not really burst, but rather tears open. Its effect on *personnel* is very small; neither is it of any use against earthworks.

Plate II. represents the section of the front face of a hasty field redoubt at Okehampton. The front parapet, 40 yards long, was 6 feet high and 7½ feet thick; the splinter-proof casemate was of similar length, and placed 13 yards in rear; the earth on the top being 4 feet thick.

It was fired at for 19 minutes, during which time 53 common were used. The effect on the front parapet was very little; for about 10 yards in length the height was reduced to about 4 feet, and at one place to about 2 feet 6 inches. Only seven shells struck the top of the casemate, and these all glanced off harmlessly.

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* See *Plate* I.

Common is used now simply as a ranging shell, for which, owing to its large visible burst, it is certainly good; at the same time, since it produces little or no effect on *personnel*, it is rather a waste; and also it is a bad principle to find the range with one shell and then change to another having a different balance, and consequently not ranging the same. No more common shell are, however, being made.

Ring.—Is an improved common, and is used by all foreign nations except the French and Germans, the latter having just given it up. It is very similar to the old segment shell, and consists of a number of rings built up and then cast iron run round them. In the experimental one of the 12-pounder there were 13 rings; the burster of 8ozs. was placed down the centre. It breaks into a large number of fragments, about 120, and has a large angle of opening. Owing to this being so large, and to the irregular shape of the pieces, the latter soon lose velocity; the dangerous space, therefore, is not very deep. The burster is, however, large enough for ranging purposes, and at the same time the shell produces large local effects. Thus 5 rounds of 12-pounder ring shells gave 343 hits on a target 60 feet by 6 feet.

It has already been introduced for the 2·5-inch mountain gun.

Case.—Is a special projectile only used in exceptional cases, about which there can be no doubt. Our case contains a very large number of bullets, but they are consequently very small, 35 to the pound. Abroad they have much larger bullets, running from 9 to 12 to the pound. On account of their lightness, our bullets soon lose their velocity, and at 300 yards the proportion of ineffective bullets is very large. Experiments have lately been made with the bullets enclosed in a wire bag, in order to make them keep together; the effect, however, was no better than before, and it seems as though one must give up the small bullets and take to larger ones. Five rounds of 12-pounder at a range of 300 yards gave only 3 throughs to 199 lodges and 31 strikes on a target 162 feet by 9 feet by 2 inches. At 200 yards there were 66 throughs to 250 lodges and 31 strikes. Cordite has further increased the difficulty of obtaining a good case shot; for cordite only acts under strong pressure, and it is found that the resistance offered by case is so little that it is rather pushed out of the gun than blown out.

Shrapnel.—This is now generally considered the field artillery shell. There are two distinct types—the head burster, represented by the 12-pounder, and the base burster, represented by the 13-pounder.

The 12-pounder shell is made of steel tubing, pressed in at the top. The burster is contained in a tin cup in the head. The bullets—177—are set in resin, and the base is rivetted on. Its time action is as follows :—When the bursting charge explodes the base is blown off, the body goes on intact, and the bullets spin out behind in a cone, forming on the ground a long oval pattern. The depth of this dangerous ground decreases as the range gets longer. When burst about 50 yards short at a range of 1,000 yards, it is about 300 by 17 ; 2,000 yards, 250 by 25 ; 3,000 yards, 200 by 29. Theoretically, it is considerably more, but I believe these are the distances that can fairly be claimed from actual results on level ground. This depth covered is what places shrapnel so far ahead of any other projectile against troops in the open. If the ground slopes to the rear the depth is increased, if to the front it is decreased and its intensity increased. Comparing the two types, one finds the advantages of the head burster are—

More bullets.
Quicker action.

Disadvantages—

Increased angle of opening.
Loss of velocity.

More Bullets.—The bullets represent the useful part of the shell, and, on account of the absence of the channel down the centre, they are more in number in a shell with a burster in the head than when it is in the base.

Quicker Action.—This renders the head burster a more efficient percussion shell, for it opens before it has time to rise, whilst when the charge is in the base the flash has to pass down from the fuze to the charge, and the time it takes doing this allows the shell to rise some distance from the ground before exploding, and many of the bullets are thrown upwards over the top of the target.

Increased Angle of Opening.—The bullets being checked by the head burster, the angle of opening is increased, thus rendering more bullets ineffective and requiring a more accurate fuze, for the larger the angle of opening, the closer to the target must the shell be burst.

Loss of Velocity.—The velocity lost by the bullets due to the retarding effect of the head burster is about 140 f.s., whereas with a base burster there is a corresponding gain. It follows, therefore, that if a base burster is used you can afford to have a gun with a lower velocity.

The French shrapnel, like ours, has a head burster, but its action is somewhat different. It contains 160 bullets and 76 segments, and the charge is contained in a cast-iron head. On exploding, it blows the whole shell open and must have a large angle of opening. They, however, appear to have accepted this as an evil that is more than balanced by the great advantage of having only one shell fairly good all round.

They are even, I believe, going further, and are considering whether they should not replace part of the bullets by some burning composition so as to be able to use it to set villages on fire. In this respect the great number of shrapnel now carried has rendered the artillery of the present day much worse off than formerly. I believe the Austrians still carry shell filled with a burning composition, and in 1866 were on several occasions able to set villages on fire *in a few minutes*. The Prussians, on the contrary, tried in vain to do so. In 1870 it was only after long-continued firing that villages were set on fire.

High-Explosive Shell.—This is a long steel shell filled with a high explosive. On exploding it is burst into a great number of very small pieces, which are projected violently in *all* directions; few of these pieces are larger than the finger nail, and their effect devastating on the spot is limited to a very short radius, one French authority (Colonel Langlòis) putting it at as little as 15 yards. The shell thus compares very unfavourably with shrapnel, having regard to the amount of ground covered. It has, however, been introduced by the French and Germans in the hope of being able to reach troops behind cover; neither propose to use it against troops in the open. The Germans advise its being used with a time fuze, to destroy the *personnel* by bursting it just over or beyond the crest, in which case the all-round effect might search the interior. The French, on the other hand, keep rather to the idea of using a percussion fuze and reaching the defenders by breaching the parapet. Up to now not much success has attended either method. The former because in field guns, the remaining velocity being fairly large and the burster small, even the high explosive does not fully overcome the forward velocity; the latter because the charge of high explosive contained in any field artillery shell is so small that its effects on earth are limited; these, although greater than when black powder is used, are still so small that to produce any appreciable effect a tremendous expenditure of ammunition is necessary. Furthermore, most are smokeless; it is very hard, therefore, to tell what one is doing. Against troops in houses it would probably be more effective.

As a consequence of the failure of obtaining results on earthworks from field artillery, even with high explosives, nations are experimenting with field howitzers, and with them better effects should be obtained in both cases, because the charge is large and velocity small. The Russians, Austrians, and Swiss have for some time possessed howitzer batteries. The Russian is a 6-inch. Its common shells weigh 60lbs., and has a burster of 10lbs. Its shrapnel weighs 68lbs., and has 683 bullets.

The Swiss have a 40lb. ring shell, with a burster of 2lbs. 2ozs. Its shrapnel, 39lbs. and 475 bullets.

The great drawback to them is their want of mobility, for although the weight of the howitzer itself may be kept within suitable limits, the ammunition cannot. The Russians carry 92 rounds per howitzer, and to do this have 36 carriages in the battery, and occupy 600 yards of road.

THE GUN.

The two great questions with regard to the gun are—

1. That of velocity.
2. Should it be a quick-firer ?

Shall the Velocity be High or Low ?—It is perhaps better to say high, or medium, for when one speaks of low velocity in a field gun one really means a velocity of about 1,500 f.s., and not one such as a howitzer has. Let us examine shortly the respective advantages and disadvantages of high velocity.

HIGH VELOCITY.

Advantages—

1. Flat trajectory.
2. High bullet velocity giving deep dangerous zone.
3. Better ricochet effect of bullets.
4. Range and accuracy.
5. Smaller bullets, and, therefore, more of them.

Disadvantages—

1. Effect on carriage.
2. Excessive recoil.
3. Inaccuracy due to jump.
4. Difficulty to obtain a good shell.
5. Difficulty of fuze.
6. Want of searching power.
7. Wide angle of opening.
8. Light shell.

Advantages.

1. *Flat Trajectory.*—No real difference when considering shrapnel fire from field guns having a velocity of 1,500 to 2,000 f.s. Also any small difference in the trajectory is neutralized by the increased angle of opening of the shell. One must remember that the trajectory of any field gun is never *flat* like that of a rifle. Neither does the effectiveness of a gun depend on its trajectory like a rifle.

In the rifle the depth of its dangerous zone depends entirely on the flatness of its trajectory. In the gun this is not the case, for the gun is judged by its shrapnel effect, and a good shell depends on many factors, *i.e.*, trajectory, position and size of burst, angle of opening, number of bullets, velocity at point of burst. In designing a gun and shell they must all be considered.

The differences in the angle of descent of a 12-pounder with muzzle velocities of 1,700 and 1,500 f.s. are :--

M.V.	1,000 yards.	2,000 yards.	3,000 yards.	4,000 yards.	Range.
1,700	1° 1′	3° 22′	6° 51′	11° 29′	{ = Angle of descent.
1,500	1° 19′	4° 6′	7° 55′	13° 5′	,, ,,
Differences ...	0° 18′	0° 44′	1° 4′	1° 36′	

and these are too small to make any appreciable difference in the effect of the shell.

2. *Greater Depth of Bullet Zone.*—This is the great advantage claimed, but at present it is hard to tell what it actually is. Up to

2,000 yards there is not much difference, but beyond that the high muzzle velocity exhibits an advantage. General Nicholson, comparing a 12-pounder shell fired with a muzzle velocity of 1,700 with one of 1,500, gives the ground covered by the bullets at a range of 3,000 yards as 291 and 206 yards respectively. Practice apparently makes both considerably less.

Further, in considering this one must remember that the velocity of the bullets and depth of ground covered depends not on the muzzle velocity, but on the *remaining* velocity of the shell at the point of burst. Now the remaining velocity depends greatly on the transverse density of the shell, that is to say, the heavier the shell and the less its diameter the longer will it preserve its velocity.

By reducing the 12-pounder velocity to 1,550, it is found that a 15lb. shell can be fired. This shell will preserve its velocity better, and at 2,000 yards is already 3 feet ahead, having at that range a velocity of 996 against 993.

By thus reducing the muzzle velocity, one has gained a greater velocity at the destructive point, *i.e.*, the enemy's end of the range, and also a heavier and more powerful shell.

Some experiments made showed that a good 15lb. shell gave 50 per cent. more hits than a good 12lb. shell, and that the proportion of effective to non-effective bullets was also greater in the former.

3. *Better Ricochet owing to Increased Velocity of Bullets.*—Here again it is a question of remaining velocity and not muzzle velocity, and in any case the advantage is very small.

4. *Range and Accuracy.*—1,500 is quite good enough for range and accuracy; by increasing it over 1,500 no further advantage is gained.

5. *Smaller Bullets, and, therefore, more of them.*—Our bullets are quite small enough; if smaller they would lose their velocity so much quicker that although they might start with a greater velocity, the dangerous zone would not be so deep.

Disadvantages.

1. *Effect on Carriage.*—High velocity causes a great strain on the carriage, and it has to be made heavier in consequence.

M.V.
1,700. Strain on 12-pounder carriage = 4,620lbs.
1,500. " " " = 3,475 "

If the present carriage is lightened by 200lbs., the strain in the latter case becomes 3,852lbs.

2. *Excessive Recoil.*—Makes it hard to keep up a rapid fire.

3. *Inaccuracy due to Jump.*—Not of much account.

4. *Difficulty to obtain a Good Shell.*—The shock of discharge being great, the shell, if of forged steel, has to be tough to avoid prematures, and as a consequence does not break up at the enemy's end of the range; if of cast metal, the wall must be thick, and thus useful bullet space is lost.

5. *Fuze.*—High velocity is very hard on fuzes. It affects the burning greatly, and at the same time, to get the same accuracy of burst, requires more accurate fuzes; since an error in the time of burning will cause a greater error in the position of the burst of a high velocity shell than in that of a low one.

6. *Want of Searching Power.*—Both are very deficient and practically alike in this respect, the increased angle of opening of the high velocity shell compensating for the increased angle of descent of the low velocity.

7. *Wide Angle of Opening.*—Requires shell to be burst closer, and, therefore, requires a more accurate fuze, which is just what high velocity prevents. At the same time, the twist of rifling has more to do with the angle of opening than the velocity. Reducing the twist of the horse artillery gun from 1 in 28 to 1 in 40 increased the effect of a good shrapnel by about 33 per cent. The 1 in 40 did not, however, centre the shell sufficiently. A twist of 1 in 35 is now being tried, but even this hardly centres the shell properly, and one will probably be forced back to the 1 in 28, unless a uniform twist which should act better with cordite is tried. Experiments abroad have shown that reducing the twist of 8-c.m. from 1 in 25 to 1 in 32 increased the effect of time shrapnel by about 25 per cent. at 2,000 yards.

8. *Light Shell.*—The carriage and gun will stand a certain strain, which increases directly with the velocity and weight of shell. If you increase one you must decrease the other. Thus with the 12-pounder, as previously stated, one can have the choice of a 12lb. shell and muzzle velocity of 1,710, or a 15lb. shell and a muzzle velocity of 1,550, and there is no doubt that the latter is the more powerful combination. Of course, if it was only a question of high or medium velocity, and one could get high velocity without its drawbacks, it would be excellent, as, other things being equal, high velocity gives a greater proportion of throughs.

QUICK-FIRERS.*

First, what is a QF.? There is often, I think, considerable misapprehension of the term. A true QF. must fulfil the following conditions:—

1. It must fire fixed ammunition and smokeless powder.
2. Breech action must be rapid and simple, and must extract the empty cases.
3. No recoil, or if recoil the gun should return to its position.
4. The layer should be undisturbed.

1. *Fixed Ammunition.*

The advantages of this are—

The Powder is better preserved.

The Case forms a good obturator, and gets rid of vents, ramming home, and our clumsy method of firing. The question of vents is a great one, for as long as the vent is not gas-sealing cordite very rapidly wears it away; with black powder the open vents last for 100 rounds or more, whereas with cordite they wear out in about a dozen. If no escape of gas takes place it is all right, but great difficulty has been experienced in doing this successfully.

On the other hand, the disadvantages of the fixed ammunition are:—

Extra Weight.—The weight of the cases is all so much dead weight. Hotchkiss has, I believe, aluminium cases which weigh only $\frac{4}{5}$ths of a pound, but it is very doubtful if these light cases will stand knocking about. We in our heavy quick-firers now have the cases separate from the shell, as it was found the cases would not stand the weight of the shell. The Nordenfelt case weighs 1lb. 10ozs. This is probably as light as is consistent with the requisite strength.

Necessity for Extracting the Cases.—This leads to the breech action being more complicated; further, there is the danger of the cases jamming should they become dented in travelling.

2. *Rapidity of Breech Action.*

This is common to all breechloaders. The 12-pounder is rapid, and the slowness of fire with it is not due to the breech action, but to the time occupied in running up, laying, and setting fuzes.

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* Appendix B gives the details of the QF.'s at present in the field.

3. *No Recoil.*

This is certainly a great advantage, both in saving labour and time. A non-recoil gun can be worked with fewer men; it also would make the protection given by a shield more efficient, since the numbers, not having to step clear of the recoil, are always sheltered. The Nordenfelt QF. is fitted with a removable shield, but I do not know where it is to be carried.

The disadvantages of the non-recoil carriage are—

Heavy lift at the trail.

Carriage complicated with a traversing gear, necessary, because the plough digs a deep hole in the ground, and after a few rounds one cannot traverse.

The Hotchkiss QF. has not the traversing arrangement, consequently after the first few rounds you cannot correct the direction without starting afresh, the designer apparently considering that as field artillery targets are as a rule broad, this is a lesser evil than a complicated traversing arrangement.

4. *The Layer should be Undisturbed.*

This latter condition has up till now not been fulfilled by any field QF. Look at the difference between a field QF. and a garrison one. *Plate* I. shows the 4·7-inch; with it the layer keeps his shoulder to the rest, and the firing of the gun does not disturb him, the sights being on the jacket, and the gun recoiling inside it. In the field carriage this is not so, and every time the gun is fired the layer and laying are disturbed. For this reason the field gun is only a "rapid loader" rather than a quick-firer.

The general design of the Nordenfelt equipment is shown in *Plates* III. and IV. In addition to the field gun, he has a horse artillery 9-pounder gun made on very similar lines.

Plate IV. shows the general arrangement of the gun and carriage.

The gun is held in a cradle, and there are two hydraulic buffers, one each side of it. On firing, the gun first recoils on the top carriage in a manner very similar to the 12-pounder on Mark II. carriage.

The breech action is very neat indeed; one simple motion of the handle unscrews the block, opens the gun, and extracts the empty case, a single motion in the opposite direction closing and locking it. The breech mechanism is also such that in case of a miss-fire the firing pin can be re-cocked without opening the breech. The carriage has a broad trail with a plough at the end; it is fitted with the Buffington brake, an American one; it is simple, and consists of an arm with a brake block at one end; the other end is fixed to the axle, and being eccentric, as the bar drops the block bites on the tyre.

There is a seat on the trail, and after a few rounds the carriage does not recoil more than a few inches; this enables the layer to remain seated: at the same time, it is not pleasant, and I doubt if men would stand it for more than a few rounds.

The ammunition wagon is ingenious, the body being a second limber hooked on to the limber proper by a short removable pole. I have not seen the results of any trials with the gun. Some time back a trial was carried out by Krupp between his 6-pounder and the German field gun, which throws a shell of 17lbs. The rapidity of fire attainable with the 6-pounder was seven to eight rounds a minute, whilst that of the field gun is laid down as two. The general result deduced was that the 17lb. shell produced twice as many hits as the 6-pounder, but that the latter, owing to its greater rapidity of fire, produced a greater effect in a given time.

The superiority of hits was gained entirely through the rapidity of fire, which was nearly four times that of the field gun. This rapidity is all very well with a single gun, but in a battery it would be quite impossible to exercise any control over the fire if it were to fire at that rate, *i.e.*, 42 rounds a minute, and the waste of ammunition would be enormous; and where is this ammunition to come from? I do not believe in this rapid unaimed fire, except for case, or a sudden attack at close ranges. On these occasions it is undoubtedly of use. And for this reason I think the general tendency is towards the introduction of a quick-firer as soon as the manufacturing difficulties have been more thoroughly overcome. With reference to rapid firing, Colonel Von Rohne (a high German authority), in a lecture delivered at Berlin, says:—"It must be an inviolable maxim, as well at manœuvres as in war, or at the ranges, that a round must never be fired until after the most careful laying. The mere explosion, simply in order to denote one's presence, the hurried discharge of a round, only to get one off before one's neighbour—which is often regarded as the highest triumph of the art, and which unfortunately is often highly commended—must be entirely banished from the drill ground, for it is the destruction of all fire discipline. Every artilleryman, down to the youngest gunner, must be thoroughly imbued with the idea that nothing is accomplished by mere noise; it is not much shooting, but much hitting, that succeeds, and this can only be attained by a careful, one might almost say cunning and cold-blooded, but never by a hurried, service."

THE CARRIAGE.

With reference to this I do not propose to say much, as it has very little to do with the actual fire. The great tendency now is to seek simplicity.

Our present Mark II. 12-pounder carriage is rather complicated. It is, however, being simplified. Thus the complicated brakes are being taken off and the drag shoe-brake substituted; this latter is very simple, and acts very well. The slow-motion traversing gear has already been taken off.

The buffer certainly still remains, and is likely to be kept on, as it works well. As to the limber, this is being lightened by only having one box. The greatest change here, however, is, as previously mentioned, the probable substitution of pole for shaft draught. This has in a great measure been brought about by the necessity of unhooking the wagon teams in action, and also because of the increased facilities which it affords in replacing casualties, every horse being interchangeable.

RESULTS.*

Let us now look at the results obtained.

First, I must warn you that only very general deductions can be made, and that figures of peace practice require very careful scanning. Thus one often sees in the papers wonderful results of some special trial, and comparisons are drawn between it and the results obtained at ordinary practice, quite overlooking the fact that at these special trials everything is done to ensure a success, the detachments are picked, targets carefully arranged, etc., whilst at service practice targets are not so arranged, and, further, directly the fire becomes effective the series is stopped.

RATE OF FIRE.

At practice the series are so short that the rate depends more on the ability of the battery commander to find the range and fuze than on the working power of the battery.

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* Appendix A.

On the 29th June, 1893, a battery fired 979 rounds, *i.e.*, nearly the whole of the ammunition with the battery and with the divisional reserve.

The total time taken was 7½ hours, of which 4¾ was actual firing, the remainder being occupied in changes of position.

The same men were employed at the guns throughout the day, and the rate of fire was as great at the end as at the commencement. A few of the men complained of gun headaches, but the only numbers who really required changing were the gun-layers, whose eyes got very tired, and it was found necessary to relieve them after every 50 rounds.

The rate of fire at standing targets varied from six rounds a minute to 2·6, the average being 4·2, which agrees very closely with foreign estimates, the German regulations laying down four rounds a minute for a 6-gun battery. For a short time at the cavalry target the rate ran up to 13·5 rounds a minute, the average at this target of the batteries practising at Okehampton being nearly 10; with smokeless powder it will doubtless be increased.

The system now introduced for meeting an attack at close ranges, 1,000 yards and under, is very simple, and is as follows:—

Previous to coming into action three shrapnel, with fuzes set at two, are placed in a portable magazine (one of the leather cases used for carrying ammunition from the limbers to the guns). When the guns are in action this magazine is placed close to the loading number. The left sight is kept fixed at 500 yards.

Suppose the battery is firing at a distant target and is suddenly attacked by cavalry at a close range. The order "magazine fire" is given; on this the guns are at once turned on the cavalry, and the three rounds per gun already prepared are fired at the fixed elevation of 500 yards. The shrapnel having their fuzes set at two burst about 400 yards from the guns, and at such a short range the bullets cover about 300 to 400 yards in depth, and with the rapid fire that can be kept up, in consequence of there being no delay setting fuzes or sights, the ground from 400 to 1,000 yards should be fairly swept with bullets. In a short time it is hoped we may be able to carry all shell fuzed and set at two, so as to be always ready for cavalry.

The effects on guns appear small, but one must remember the ranges are long, and that a battery is a very difficult target, the 40 dummies being spread over 100 yards of front.

The guns on the Bluff are, further, in a very difficult position to range on. There is a hollow in front of the target as well as in rear, and shell pitching in front, not being seen, are often wrongly observed, thus throwing out the ranging.

Now at long ranges the effect of the fire depends chiefly on good observation, so that ranging may be accurate. Any position, therefore, that is deceptive, and renders observation difficult, is good, better even than cover by earth when the latter renders observation easy.

Better results are often obtained at guns in gun-pits than when in the open, the reason, of course, being that the earth of the pits is, as a rule, clearly visible. The experience of war exhibits the same results.

Thus General Brialmont says:—"Wherever they may be placed, epaulments should be concealed by natural or artificial cover.

"The first day at the battle of Noisseville Bazaine placed behind earthworks the guns near the road leading from Fort St. Julien towards St. Barbe. These had to be promptly withdrawn, after heavy loss, whilst three batteries on the same heights, without any protection, were enabled to continue in action for some time." Again, Hoffbauer, speaking of Gravelotte, says:—"The earthworks that the French threw up to cover their batteries on the heights of Montigny la Grange and La Folie were very conspicuous, and rendered easy the ranging of the German guns."

Also, in taking up a position behind a hedge, it is best for the guns to be some distance back, and let them fire over it, the hedge acting simply as a screen. It may be necessary to cut down part of the hedge to see through, or, as was the case of the two batteries of the Guard corps artillery at Sedan, to prevent their own shells bursting in the trees.

A modification of the ripple parapet has been tried, and it certainly makes it very hard to range. It is quite different to the ripple parapet tried at Lydd a few years back. There the ripples were close together, and were designed to act as a protection rather than a mask. As a protection it was not a success, but as a mask, the ripples being merely small ridges about 2 feet high and some distance apart, it appeared successful.

Good results are almost invariably obtained at columns, owing to the depth not rendering accurate ranging so necessary, and when one has depth and breadth the results rise rapidly. In India one of the targets for the competitive consists of a line of three columns of fours of 30 dummies each, with 25 yards interval between the columns. The exact range is unknown, but is between 2,200 and 2,600 yards. A battery is allowed to fire for six minutes. I have only seen the results of four batteries, and the average number of hits obtained in the six minutes was 1,065, the number of rounds fired averaging 42.

Results rise rapidly as the range decreases, first because observation becomes easier, and secondly because the increased depth of ground covered by the shrapnel bullets renders such correct ranging and fuzing unnecessary.

This is shown by the results of the two series fired at dummies placed in echelon to represent an advance. On the first occasion 15 dummies were placed at six ranges to represent an advance from 1,700 to 800. The fire was turned from one to the other without a pause, a Staff officer giving the times. The total time in action was 23 minutes, during which time 66 rounds were fired and 74 dummies hit out of 90, notwithstanding that, owing to the paucity of shrapnel, 20 of the rounds were common shell.

In the second series, fired by the 38th, a 4-gun battery, the dummies were placed in echelon at eight different ranges. The total time in action was 19 minutes, during which 69 rounds were fired and 62 dummies hit out of 86. The time each target was under fire was estimated to be the same as infantry would have taken to advance from one to the other.

They were certainly not too long, as on the day of the field firing the infantry took from 50 minutes to an hour doing the same distance. It is also harder having several targets arranged in echelon than if they were actually advancing, because the battery commander did not know the drops, and time is also lost changing the laying from one target to the next.

At Glenbeigh the results are almost invariably higher than at Okehampton; this is due to the influence of the ground, it being favourable to ricochets. It has been proved, both theoretically and practically, that one obtains from 30 to 40 per cent. more hits when firing time shrapnel over ground favourable to ricochets than when all ricochets are stopped.

An interesting experiment was tried at Lydd last year. The coastguard station was partially defended, and then fired at with percussion common and percussion shrapnel. Part of the front had two feet of loose brick and the other part had loose shingle; the windows were boarded inside and out and the space filled with shingle. It was first fired at from a range of 2,400 yards with percussion shrapnel; 40 rounds were fired and 31 hits obtained; 10 of the rounds were, however, fired with cone-shaped cartridges, and five of the misses were included in these ten rounds.

The shrapnel went through the wall (14 inches thick), making a hole about 9 inches diameter, and then burst. The bullets entered wood, but, as a rule, did not lodge. The effect was the same when shell passed through the window, but it also blew down the inside boarding, and the shingle all fell into the room. The loose bricks stopped the shell at about the depth of a foot.

Twenty rounds were then fired at a range of 1,500. The general effect of shrapnel at this range was greater than at the former, the shells passing through the outer walls and knocking holes in the partition walls. With the common shell there were 11 hits; in one position, two hours' defence, three hits were obtained, and the damage was such as to render it untenable; the front wall was wrecked, and the whole of the partition wall between front and back brought down. These results seem to show that the most we can do with shrapnel is to keep the front rooms clear, and that, as common shell is abolished, a high-explosive shell is necessary to thoroughly destroy buildings.

APPENDIX A.

RESULTS OF PRACTICE AT TARGETS REPRESENTING ADVANCING INFANTRY.

Battery.	Times.		Approximate Range.	Rounds.	Effects.		Targets.
	Min.	Sec.			Hits.	Dummies.	
14th Field ...	3	30	2000	8	18	11	15 standing dummies.
	3	32	1800	9	52	12	,, ,,
	4	30	1500	12	113	15	,, ,,
	3	35	1250	11	58	10	,, ,,
	2	35	1200	6	34	13	,, ,,
	5	30	800	21*	13	13	,, ,,
Total ...	23	12		67	288	74	90 ,, ,,
38th Field ...	2	30	1800	8	8	7	12 standing dummies.
	2	10	1700	7	20	11	,, ,,
	2	30	1550	8	26	11	,, ,,
	2	0	1450	8	32	9	10 ,, ,,
	3	3	1200	11	31	7	,, ,,
	2	15	1100	10	13	6	5 ,, ,, 5 kneeling ,,
	2	15	950	8	14	5	,, ,,
	2	15	800	9	11	6	10 ,, ,,
Total ...	18	58		69	155	62	86 ,, ,,

* 20 common shell, dummies blown to bits.

General Idea :—Battery in action and firing, suddenly ordered to turn on to infantry advancing on the battery.

Targets placed in echelon to represent this advance; the fire being continued from target to target without a pause.

APPENDIX A.—(*Continued*).

Battery Station.	Year.	No. of Series.	Average time in action.	Range.	No. of Rounds.	Effect.		Hits per Shell.	Men hit per Shell.	Percentage of targets destroyed per minute in action.	Target.	Remarks.
						Hits.	Men.					
			″		**ARTILLERY IN THE OPEN.**							
Okehampton	1892	18	12	2960	25	86·4	9·8	1·456	·392	2·268	6 guns, 3 wagons, and 36 standing dummies.	On Bluff.
„	„	15	13 30	3320	25	14·46	8·3	·578	·332	1·707		„ Yes Tor.
„	1893	12	11 18	2845	21	19·8	9	·825	·373	2	6 guns, 3 wagons, and 40 standing dummies.	„ Bluff.
„	„	12	10 30	3285	24	91·6	10 16	·9	·423	2·41		„ Yes Tor.
„	Average of	52	11 49·5	2845 to 3320	21·5	22·9	9	·93	·37	2		
					KNEELING DUMMIES IN LINE.							
„	1892	39	6 42	1300 to 700	20·7	53·5	28·9	2·58	1·39	3·32	15 standing 15 standing	
„	1893	36	7 10		21	108·3	41·58	5·16	1·98	4·46	100 kneeling.	In one series in 1 93 the supports were kneeling.
					STANDING DUMMIES IN LINE.							
„	1892	15	8 20	2000	24·75	100·5	34	4·06	1·37	5·12	80 dummies in 4 groups, 25 yards between groups, 1 pace between dummies.	
„	1893	12	8 30	2000	23·7	54·1	25·6	2·28	1·03	3·76		
					COLUMN OF FOURS.							
„	1892	15	6 24	2470	13	96·1	26	7·39	2	5·12	50 standing dummies.	
„	1893	12	6 30	2410	13·9	79	23·25	5·68	1·67	7·15	„ „	
„	„	12	6	1780	12·9	216	36·6	16·75	2·83	12·2	„ „	
„	1892	11 6-gun	...	3000	25·5	53·1	26	2·08	1·02	...	45 „ „	
„	1893	15	6-gun, 6′ 38″ 4-gun, 7′ 30″	2500	20·4	108·07	29	5·29	1·42	...	„ „	
Glenbeigh ...	1892	3 6-gun	...	3000	25·3	...	27·5	...	1·08	...	„ „	
„	1893	5	...	2500	21	113·87	29·75	5·42	1·41	...	„ „	
				AVERAGE RESULTS OF BATTERY SERVICE.								
Okehampton	1889	...	17 0	2231	20·5	68·4	17	3·1	·331	2·17	46 dummies.	
„	1890	...	12 11	2325	20·91	43·7	17·7	2·08	·806	2·98	49 „	
„	1891	...	11 57	2331	25·79	48	18	1·5	·697	3·43	43·67 „	Including Competitive.
„	1892	...	8 3	2285	20·97	48·2	19	2·3	·91	3·65	61·2 „	Including Competitive & under cover.
„	1893	...	7 58	1938	21·17	89·24	29·22	4·24	1·38	5·07	72·5 „	Including Competitive.

APPENDIX B.

FIELD QUICK-FIRERS.

		Krupp 2·36 in. QF. Field Gun.	Hotchkiss 2·95-in. QF. Field Gun.	Nordenfelt 3-in. QF. Field Gun.
Gun.	Length, ins.	90·55	84·46	88
	Breech action	Modified wedge	Hotchkiss	—
	Twist of rifling	Increasing 1 in 25	Uniform 1 in 25	1 in 25
	Weight	5cwt. 3qrs. 17lbs.	7cwt. 8lbs.	6cwt.
Carriage.	Traversing gear	Nil	Nil	Sleeve somewhat similar to that formerly carried on 12-pr.
	Brakes	Nil. Plough on trail	Nil. Plough on trail.	Buffington and plough on trail
	Weight	10cwt. 2qrs. 14lbs.	8cwt. 1qr.	12cwt. 2qrs. 19lbs.
	Height of axis of gun	3ft. 5ins.	3ft. 2ins.	3ft.
	Height of wheels	4ft.	4ft 8ins.	4ft. 9ins.
	Weight	...	...	2cwt. 3qrs. 9lbs.
	Track	4ft. 10ins.	4ft. 6ins.	5ft.
Ammunition.	Weight of shell	6lbs 10ozs.	13lbs.	12½lbs.
	Shrapnel	100 bullets	231 bullets	—
	Shrapnel bursting charge	1·05ozs.	3·2ozs.	—
	Charge	10ozs.	1·75lbs.	12¾ozs.
	Weight of case	2lbs. 8ozs.	·825lb.	1lb. 10ozs.
	Weight of round complete	9lbs 13ozs.	15·8lbs.	14lbs. 15ozs.
Limber.	Rounds carried	48	48	36
	Total weight behind team	31cwt. 2qrs. 19lbs.	31cwt. 16lbs.	31cwt.
Wagon.	Rounds carried	...	96	72
	Weight behind team	...	31½cwt.	—
Muzzle velocity		1640	1740	1575
Recoil		None after the first few rounds, but the gun has to be relaid.		

PLATE. I.

ELD AND PEDESTAL.

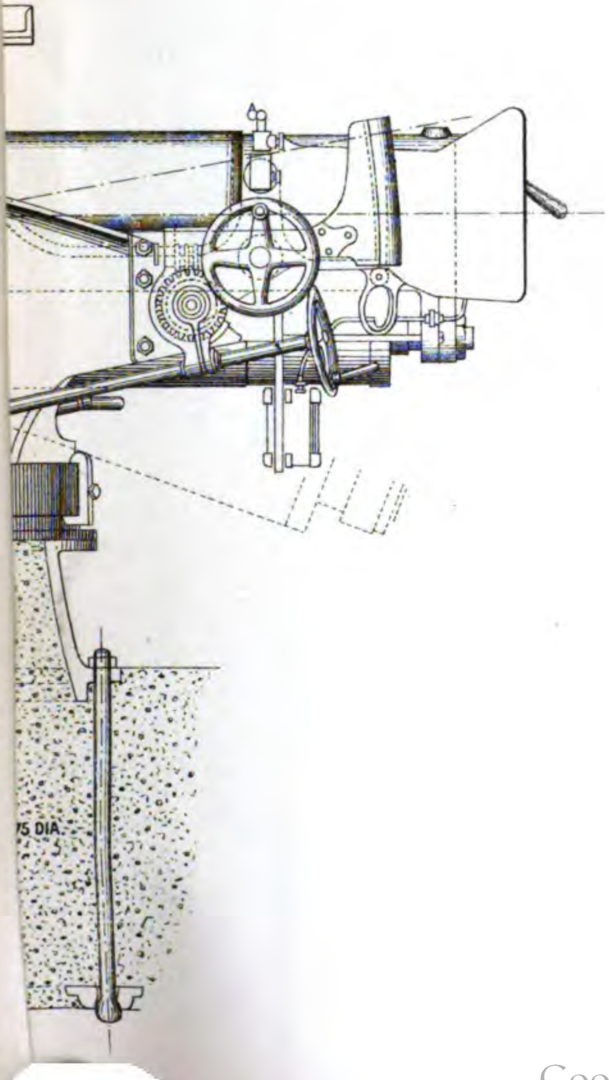

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PLATE. II.

FIELD

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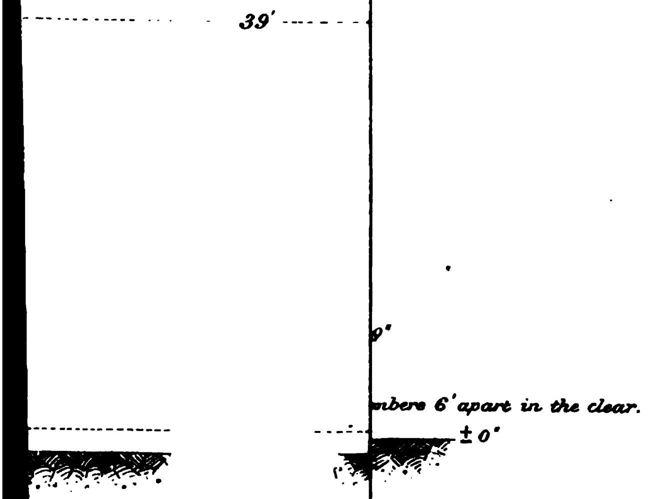

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PLATE. III.

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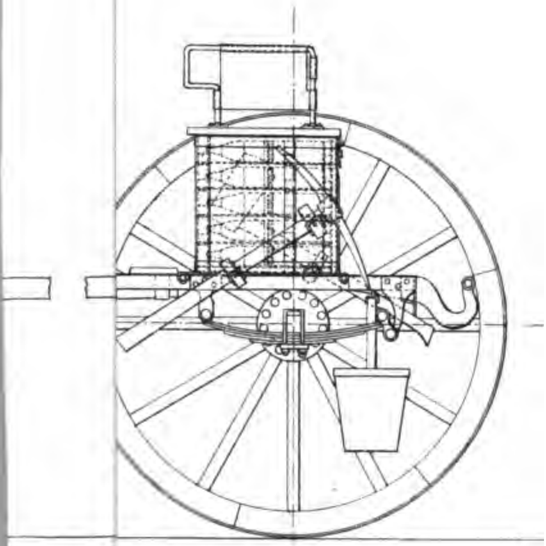


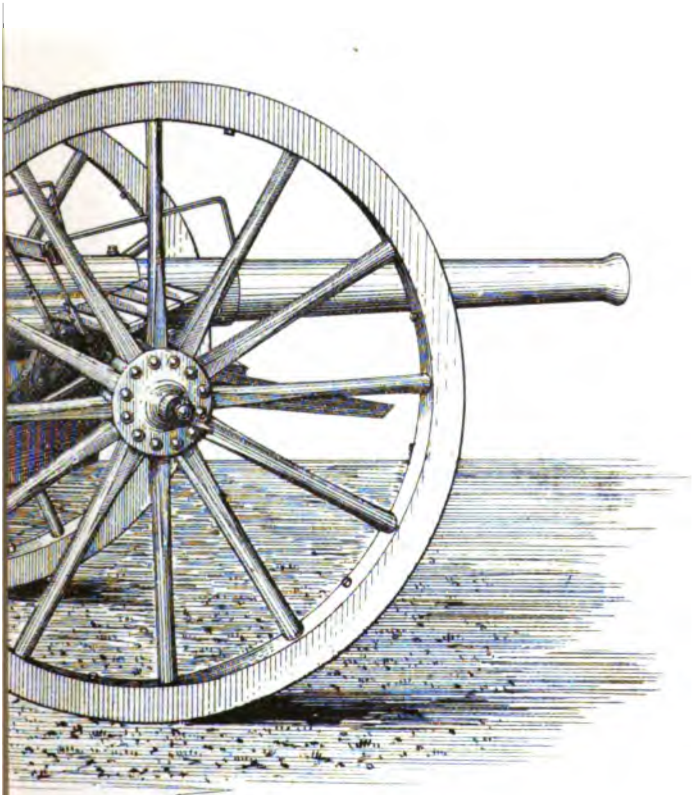
HAMPTO

Q.F. 3"

PLATE. IV.

AMPTON EXPERIENCE.

. F. 3" (12½ Pds).



PAPER II.

ELECTRIC CURRENTS OF HIGH PRESSURE AND PERIODICITY.

By A. A. C. Swinton, Esq.

The experimental effects that I propose to show this afternoon are all produced by utilizing the disruptive discharges of Leyden jars to give electrical impulses of comparatively considerable magnitude as regards energy, but of exceedingly short duration as regards time.

As is well known, if a Leyden jar be discharged through a stout copper wire forming a circuit of small resistance, a surging of the electrical charge is set up, with the result that the electric current which passes through the wire is of the nature of a gradually dying away oscillation. The action may, indeed, be compared to what occurs when a pendulum, immersed in some viscous fluid, is suddenly released from an inclined position and swings backwards and forwards with a gradually decreasing amplitude of oscillation until it comes to rest. Or we may make the analogy more exact by comparing the effect to a loaded spring bent aside in a resisting medium and then let go. The pliability of the spring corresponds to the capacity of the condensor, its displacement to the electrical charge, the load or inertia to the self-induction of the circuit, and the viscosity of the fluid to the resistance of the circuit.

Thus the total duration of the discharge of a Leyden jar varies with its electro-static capacity, being longer for large jars than for small. At the same time, both the duration of the discharge and the rate of oscillation are dependent upon the resistance and self-induction of the discharging circuit. In apparatus of the kind that we employ the conditions are exceedingly complex, and consequently calculations as to the duration of the discharge, or as to its rate of oscillation, must necessarily be only approximate. The total duration of the discharge itself can, however, be fairly accurately measured experimentally by means of a revolving mirror, and I think you may take it as tolerably correct when I tell you that the total duration of each discharge of the batteries of Leyden jars that we have here, and are going to use, is about $\frac{1}{50000}$ of a second. It has further been calculated that, with the conditions that we are working under, the rate of oscillation should be about 200,000 complete periods per second, so that apparently we get about four complete oscillations in each of our discharges.

Our jars are charged by means of an alternate current dynamo machine, which has a frequency of approximately 100 complete alternations per second. The jars are charged and discharged at each half-period, consequently once in each $\frac{1}{200}$ of a second. The duration of the discharge is, as already mentioned, $\frac{1}{50000}$ of a second, and consequently, if we devote our attention merely to what is taking place in the discharging circuit, there are intervals between each discharge of $\frac{249}{50000}$ of a second, during which intervals there is no current passing at all.

Fig. 1 shows this from a diagrammatic point of view. Only four discharges are shown, and it has unfortunately not been possible to show the intervals between them to scale, as, if shown on the same scale as the discharges, each of which on the diagram occupies 10 inches, the intervals ought to be no less than 208 feet.

It has been usual to call oscillatory currents produced in this manner *high frequency* or *high periodicity electric currents.* I am not sure with whom the term originated, but I think it was with Mr. Tesla, to whose investigations in this particular branch of electrical science we all owe so much. I am bound to say, however, that the term seems to me to be a very unfortunate one, as, though the periodicity is decidedly high during each discharge, the discharges are of so very short duration, and are spaced by such comparatively long intervals, that the average frequency is really not high at all; in fact, in the experiments I am about to show you, the average frequency appears only to be about 800 a second as against 100 a second, the periodicity of the alternator supplying the original current.

Further, and what I am now going to say is, I believe, in direct contradiction to the orthodox view, it does not appear to me that any high frequency at all is necessary to explain the effects produced. All that is necessary is that the electric current should be delivered in impulses of exceedingly short duration, in which the current and voltage rise from zero to enormously high maxima, and fall again to zero with exceeding suddenness. The effects are, in fact, due to the rapid rate of change.

Now oscillatory or pulsatory currents of the description that I have mentioned behave in many respects in quite a different manner from continuous or ordinary alternating currents. This is due to the fact that while with ordinary alternating currents the effects of impedence, induction, and electro-static capacity are comparatively small, unless we take special means to render them operative, with our oscillatory currents these effects are comparatively enormous, and show themselves whether we will or no.

To take first of all the case of impedence. We have here a thick copper wire bent into a U-shape, which would conduct an ordinary alternating current with practically no impedence at all. We have it connected as shown in *Fig.* 2. We start with a 100-volt alternating current of the ordinary description, which passes through the primary of an induction coil. From the secondary of this coil we obtain some 20,000 to 30,000 volts. This high pressure current charges the Leyden jars at each half-period up to a point where the air resistance across the spark gap is broken down, and a disruptive oscillatory discharge takes place. In this manner we obtain an oscillatory discharge of electricity through our U-shaped piece of copper wire. In order to let you see the effect of the impedence, I will connect these incandescent lamps across from one leg to the other of the U-shaped wire. You will observe that though short circuited by the wire, which has enormously less ohmic resistance than the lamp filaments, the latter incandesce brightly. The oscillatory current, in fact, does not take the path of least ohmic resistance, as might be expected, but the shortest path, *i.e.*, that of least self-induction and impedence. By sliding the lamps up and down we can make them burn more or less brightly, and by choosing suitable positions we can make lamps varying in voltage from 20 to 100 volts all burn with uniform brightness.

Again, oscillatory electric currents such as those with which we are dealing have much more powerful inductive effects than ordinary alternating currents.

We have here two circles, each consisting of a single convolution of thick copper wire. One of these circles has a 20-volt 5-c.p. incandescent lamp connected to the two ends of the wire, and the other circle is connected as was the U-shaped wire in the last experiment, so that we can send oscillatory discharges through it. We will hold the two circles facing one another about six feet apart, and turn on the current. As you see, the lamp filament is gradually becoming red hot, showing that the oscillatory current passing through the one circle is inducing an electric current in the other. If we bring the circles nearer together, the lamp becomes brighter, and with an interval of two feet the lamp is fully incandesced.

One of the most striking facts in connection with these oscillatory currents is the small physiological effect that they appear to have on the human frame. As is well known, the discharge of a good-sized Leyden jar, if taken direct, occasions a most violent shock to the system, and may, indeed, be sufficient to destroy consciousness for a time, or even to cause death. The current from a medical magneto machine, or even a small induction coil, is sufficiently unpleasant for most people, while that from an alternate current dynamo giving 1,000 to 2,000 volts is used for official electrocution in the United States of America, and has been the cause of more than one death in this country. The electric currents employed in medicine rarely exceed a few thousandths of an ampère, muscular fixation and other unpleasant results being usually produced when more than 10 to 20 milliampères of continuous, or 2 to 6 milliampères of alternating or interrupted current is passed through the body.

We have here an ordinary 5-c.p. 100-volt lamp, which, with continuous or ordinary alternating current, requires about one-fifth of an ampère or 200 milliampères to bring it to full incandescence. This is, of course, a much greater strength of ordinary current than anyone could bear for a moment. We will incandesce this lamp with current conveyed through the bodies of two persons. The connections are as shown in *Fig.* 3, and, as you will observe, there is no connection between the lamp and the other apparatus except through the arms and bodies of the two operators. As you will see, the lamp filament is brought up to full incandescence when we turn on the current.

Various theories have been propounded to account for the harmlessness of these currents. Some have supposed that the human body acts not as a conductor, but like a condensor with regard to the passage of alternate currents, forgetting that were this the case the impedence offered to oscillatory currents would be very small, and the application of high voltages such as I have been using would consequently be serious. Some, on the other hand, have imagined that it is all a question of the nerves, which they assume to be, as it were, tuned only to respond to alternations of comparatively low periodicity, and being unaffected by those above a certain range, as is the eye to luminous waves above the frequency of violet light.

The real facts of the case seem to be that wherever these oscillatory currents are harmless it is simply for the reason that the quantity of electricity they transmit in any given time is too small to do any injury. Leaving on one side those physiological effects which from the burning and disruptive action produced in the tissues transversed are clearly due to the internal production of considerable quantities of heat, the physiological effects of electric currents seem most probably to be due to chemical decomposition; in fact, to electrolysis. Now the amount of electrolytic effect in any given time is, of course, proportional to the quantity of electricity, that is to say, to the number of coulombs passed in that time. What, therefore, can be more natural than that the physiological effects of electric currents should, within limits, be proportional to the coulombs of electricity passed.

It will, however, be said that in the lamp experiment I have just shown you the current in the lamp must have been one-fifth of an ampère, and that consequently whatever the description of the electric current, continuous, alternating, or oscillatory, one-fifth of a coulomb was passed through the arms and bodies of the operators during each second that the lamp was lighted.

A little consideration will, however, show that this is by no means the case. In the first place, as has been shown by Lord Kelvin, oscillatory currents which rise and fall between minimum and maximum very rapidly do not flow uniformly through the section of a conductor. They tend to keep on the surface, and given sufficiently sudden fluctuations, may only be, as it were, skin deep. Applying this to the filament of our lamp, the effect is to increase its resistance, since only a part of the section of the filament acts as a conductor. The filament might, in fact, be a hollow tube instead of a solid wire. We have an ample sufficiency of available voltage, and though the strength of the current may be small, the resistance being high there is a sufficient expenditure of watts to raise the filament to incandescence. The lamp, in fact, ceases to be a 100-volt lamp taking one-fifth of an ampère, and becomes, may be, a 1,000-volt or even a 10,000-volt lamp, taking only a tenth or a hundredth of that amount of current.

There is also another point to be borne in mind. The current is delivered in impulses of exceedingly short duration. If we turn to *Fig.* 4, the double cross shaded portion of the figure represents a current of two ampères flowing for one second of time. The area of this portion thus represents two coulombs of electricity. If we assume that this current is being passed through a resistance of one ohm, the heat generated in the resistance will clearly be equal to two joules. So much for continuous current. If we now turn to *Fig.* 5, we have a similar quantity of electricity, namely, two coulombs, passed through a similar resistance of one ohm, but instead of sending the current through continuously for one second, we will suppose it to be sent through in four pulsations, each lasting for one-tenth of a second, with intervening spaces of one-fifth of a second of no current at all. In order to pass our two coulombs within the second under these conditions, the average current during each pulsation will have to flow at the rate of five ampères, and the amount of heat generated, being proportionate to the square of the current, will be one and a-quarter joules for each pulsation. The total heat generated during the second will, therefore, be equal to five joules, as against the two joules generated when we employed a steady current. Conversely, of course, the same quantity of heat can be generated in a given resistance and in any given time with a pulsating current with a less quantity of electricity than will generate this quantity of heat in the same time with a steady current. Further, the shorter the duration of the impulses the smaller is the quantity of electricity necessary, so that when we come to impulses of such exceedingly short duration as $\frac{1}{50000}$ of a second. such as we have been using in our experiments, the quantity of electricity necessary to produce the amount of heat required to incandesce our 5-c.p. lamp must be exceedingly small indeed.

So far we have been dealing with what I may term *primary oscillatory currents*, namely, currents that are derived directly from the Leyden jars without transformation. We will now try the effect of a step up transformer which is contained in this box, and is entirely immersed in resin oil, in order to prevent sparking and the dissipation of energy by leakage either in the shape of con-duction or brush discharges. The arrangement of the connections may be as shown in *Fig.* 6.

We are now dealing with oscillatory discharges having a potential difference that may be measured in hundreds of thousands of volts, and, as you will notice when the light is put out, the brush discharge effects are very striking. If I present my hand to one of the terminals of the coil, sparks shoot out to my fingers. These sparks cause a painful pricking, but if I take a piece of metal in my hand and present it to the terminal I can take a violent discharge of sparks practically without any sensation. If I take hold of one terminal of the coil with one hand, which I can do without hurt, and present the other hand to the outside of the box of oil containing the coil, streams of sparks issue from my finger tips. Again, having hold of one terminal I can draw sparks from any body having electro-static capacity, such as another person or any metallic body, merely by bringing my free hand, or for that matter my foot or any part of my body, near to them.

The high tension oscillations have also marked electro-static inductive effects. We will show this by attaching a tin plate to each of the two terminals of the coil. We have here two other tin plates, between which an incandescent lamp is connected. When we bring these latter plates within a foot or six inches of the others, the lamp incandesces brightly. We can also incandesce a lamp filament by connecting one lamp terminal to one coil terminal and merely touching the other lamp terminal with a piece of metal held in the hand. The operator can stand upon an insulated stool, it makes no difference, as the effect is due not to any circuit being established, but to the electro-static capacity of the operator's body. The electricity, in fact, merely runs in and out of the operator through the lamp, and thereby incandesces the latter.

Pretty effects can be shown by passing the high tension discharge through a piece of wood, the sparks finding their way through the substance of the material and lighting it up with a dark red colour. Or a piece of glass, one side of which is covered with tinfoil, may be placed between points connected to the terminals of the coil. As will be seen, the discharge spreads out in fiery streamers over the glass with a loud roar. By substituting a dry photographic plate for the glass we can obtain photographs of the discharge taken with its own light. I have had lantern slides made of photographs produced in this manner, and, as you will see, they give very beautiful effects. The figures produced by positive electricity are irregular, somewhat resembling the rivers on maps ; those produced by negative electricity are, on the other hand, beautifully curved, and are like feathers or palm branches. Oscillatory discharges show both positive and negative figures combined.

The oscillatory electro static stresses set up in the neighbourhood of the coil will also produce luminosity in vacuum tubes. If I wave the tubes rapidly you will notice the discontinuity of the light, which is due to the intervals of time between the succeeding groups of oscillations. I have here a cylindrical vacuum tube outside of which is wound a few turns of thin wire in the form of an open spiral. I connect one end of this wire to one terminal of the coil, and you see two luminous spirals twisting in and out of each other. One is the wire, which glows with a dark purple colour ; the other is a species of ghost, produced by molecular bombardment inside the tube.

The luminosity of wires can, however, be shown on a larger scale. We have here two circles of wire, a large and a small one. We will connect them respectively to the two terminals of the coil, and place them concentrically in one plane. When we switch on the current and lower the gas you will see that both wires glow brightly, while the interval between them is filled with streamers of purple light. Or we can connect these two parallel wires which reach to the other end of the lecture hall, and which become luminous throughout their entire length.

These are all the experiments I have to show to you this afternoon. These phenomena may not in themselves have any immediate useful application, but they are in many ways very instructive. In addition, the essence of science is the correlation of facts, and the further we pry into the secrets of nature the more we are likely to achieve useful results.

IRE & PERIODICITY. **PLATE. I.**

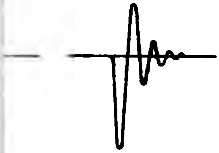
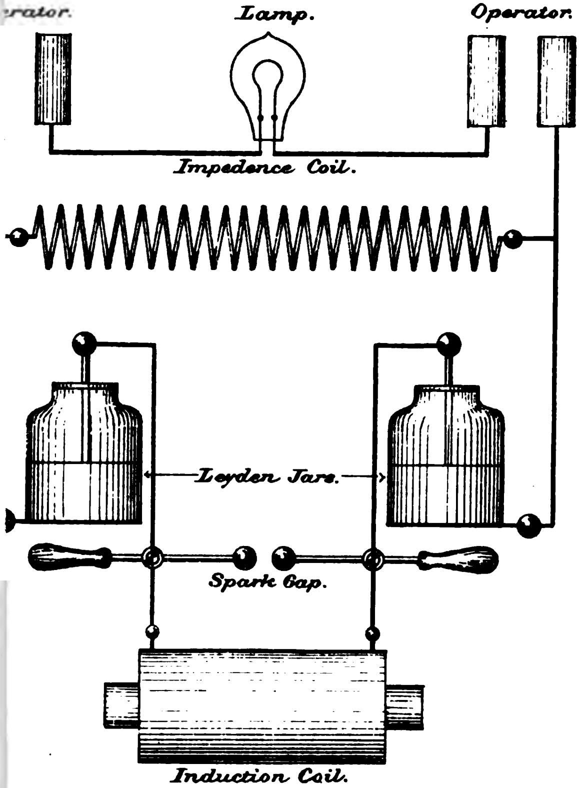
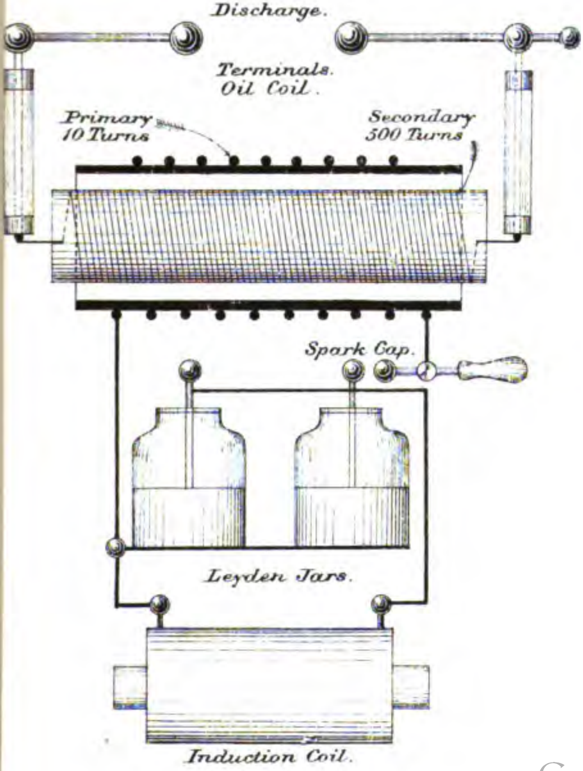


Fig. 3.



antity. 2 Coulombs.
Ampères.

Fig. 6.



PAPER III.

THE OLVUSÂA SUSPENSION BRIDGE.

By Major H. Appleton, R.E.

TRAVELLING in Iceland in the summer of 1894, I had occasion to cross the Southern Hvita, or White River, at Olvusâa by the suspension bridge lately completed at that point.

The almost total absence of oscillation as my party rode over, notwithstanding the very light look of the bridge, led me to examine it closely, and I found so many points of interest in the design that it has seemed to me a detailed account of it may be of service to brother officers called upon to design similar works.

In addition to the special means adopted to secure freedom from vertical oscillation, which I believe to be original, lightness and portability, interchangeability of parts, and facility of erection with a minimum of skilled labour or use of any but the simplest appliances, *i.e.*, all the conditions that should be had regard to in the design of such works for military purposes or for use in remote uncivilized countries, have been studied very completely in the design.

The engineers, Messrs. Vaughan & Dymond, of Newcastle-on-Tyne, have kindly furnished me with the drawings and particulars upon which this report is based. They are, I believe, constructing a series of similar bridges for the Danish and Norwegian Governments, and hence have special experience in the subject.

DETAILED REPORT.

General and Site.—The bed and banks of the river at the site of the bridge are of lava, affording a firm foundation for the piers and abutments, which are so placed as to give one clear span of 246′ and a half-span of 123′, the waterway in ordinary times being confined to the former.

The velocity of the river is, when not in flood, about 10 miles an hour.

All material, including the cables, had to be carried by hand from the nearest port, Eyarbakki, which is some miles off, there being no road.

The bridge is adapted for light-wheeled and pack-animal traffic, and has a clear width of roadway of 8′ 6″.

A general plan and elevation of the bridge is shown in *Figs.* 1 and 2, *Plate* I., and cross-section in *Fig.* 3, *Plate* IV.

The Foundations.—The masonry bases of the piers are of coursed rubble of lava stone in cement mortar, ashlar bed-plates for the shoes of the steel piers, anchors and road-bearers being built in as shown in the drawings.

Figs. 1, 2 and 3, *Plate* II., show the details for the centre pier.

Anchorages.—The cables are connected to the anchors at roadway level, *Figs.* 12 and 13, *Plate* V., showing details for the whole-span end, and *Figs.* 1 and 2, *Plate* III., and *Figs.* 4, 5 and 14, *Plate* V., details at the half-span end.

Saddle or knuckle brackets were necessitated in the latter case, owing to the change in direction to the anchors, and the use of these led to the variation in design of the holding-down bolts. The anchorages are open to inspection.

The Piers.—The piers are of steel, the verticals being of 6″ × 6″ × ¾″ angles, braced with 3″ × 3″ × ½″ tees and 6″ × ⅝″ bars. The cap is of ¾″ plate. The feet rest on shoes 1½″ thick.

At the centre pier, the reciprocating angle of the cables causing a considerable thrust inwards, the heads of the two portions of the pier are connected by a cross-lattice box girder. This is, of course, unnecessary at the end pier, the thrust due to the cables being there vertical.

Figs. 4 and 5, *Plate* IV., show details of the centre piers and method of securing them to the bed-plates, and *Figs.* 1 to 3, *Plate* II., show the arrangements for the road-bearers at the same point.

The details of the rivetting are shown in the drawings.

Saddles for Cables.—The cable-bearers or saddles are quadrants in form, and are mounted on trunnions. This form of saddle is found to be advantageous during erection, and much simpler than the rollers usually adopted, and is one of the special designs of this firm.

Figs. 1, 2 and 3, *Plate* V., show the details. It will be observed that the centre pier saddles require to be in the direction of the stress caused by the cables.

The Cables.—The cables were supplied by Messrs. T. & W. Smith, of Newcastle-on-Tyne.

Neutralization of Oscillation.—To neutralize vertical oscillation, it was decided to use three cables, laid side by side, on either hand, the centre cable in either case being of equal strength to the other two. By suspending the roadway from the main cable and the two smaller ones alternately, any oscillations set up would neutralize each other.

Specification.—The main cables, 404½′ long, are of 3·045″ diameter, and are composed of 7 strands arranged 6 over 1, each strand containing 37 wires arranged 18 over 12 over 6 over 1, each wire being of ·145″ diameter.

The smaller cables resemble the main ones in all respects except that the 18 covering wires are omitted, thus leaving 19 wires per strand instead of 37.

The quality of wire employed was best crucible steel, galvanized, with a tensile strength of 90 tons per square inch. This gave a total breaking strain of 340 tons for the main cables, and 170 tons for the smaller cables. Each of the main cables weighed over 3 tons.

Attachment to Anchorages.—The method of attachment of the cables to the anchors is as shown in *Figs.* 12 to 14, *Plate* V. The ends of the cables were first prepared by unreeving them for a short length; each set of strands was then bent over wedge-pieces previously laid along the cable, the wires being cut off at successive lengths in the clip, so as to give a uniform taper to the end. The clips of cast steel, heated in the middle, were then bent over the cable, and the steel rings Nos. 2, 3, 4, etc., which were already on the cable, were driven up. They, necessarily, were put on cold. The outermost ring, No. 1, was driven over the end hot and shrunk on.

Suspending Rods.—The suspending rods, placed 6′ apart, and of 1″ diameter, are of two patterns, viz., as in *Figs.* 7 and 8, *Plate* V., for use with the single cable clips, *Fig.* 6 (A), same plate, and *Fig.* 9 with the double cable clips *Fig.* 6 (BB).

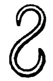
Roadway.—The roadway consists of a double layer of planking on timber road-bearers carried by steel girders $5'' \times 3'' \times \frac{7}{16}''$ in section.

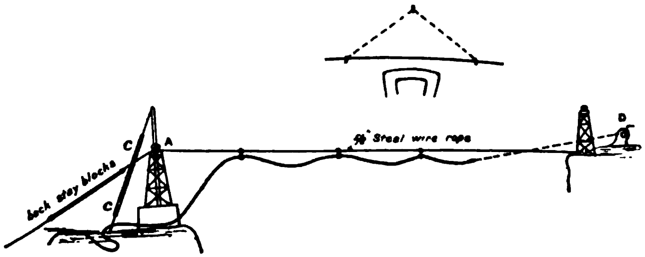
The details of the hand-rails and method of connection of the suspending rods to the roadway, etc., will be apparent from the drawings (*Figs.* 1 and 3, *Plate* IV.).

Wind Bracing.—Diagonal bracing of $3'' \times \frac{1}{2}''$ bar is provided for wind (*Fig.* 2, *Plate* IV.).

As an instance of misdirected zeal, I may note that the local authorities, in the absence of engineering opinion, have attempted to stop the small swinging that must exist in high wind by staying the roadway with steel ropes.

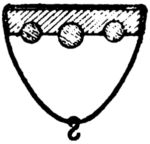
All connections in the roadway were made with bolts.

Erection.—The Cables.—The method of erection employed was as follows, viz.:—A $\frac{5}{8}''$ diameter steel rope was stretched from the top of one pier to the bottom of the opposite one, and a derrick of suitable length was erected to plumb over the centre of one quadrant. Having attached the cable end to the anchorage, a tackle was attached to the cable some 30′ back. It was then hoisted to position A, and placed in a  resting on the $\frac{5}{8}''$ rope. The length was then hauled out by means of the winch D, the operation being repeated till the cable was across, when the end was made fast to the anchorage on the far bank. A sling chain was then attached to the cable and it was lifted into position on the quadrant.



The accompanying sketch will make the operation clear. It was found that two cables could be got into position each day.

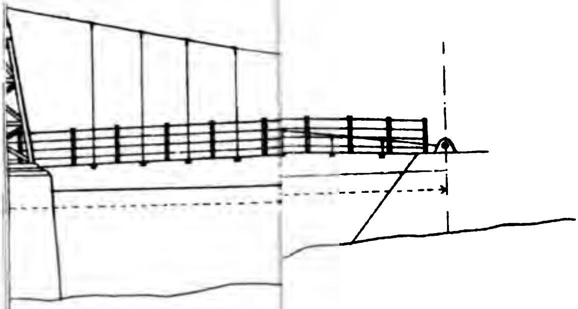
The Roadway.—To enable the roadway to be built out, a platform hung from the cables by the four corners, and provided with tackle to raise or lower it to the required level, was used. The top blocks were attached to cast-iron plates with grooves to suit the centres of the cables, so as to have them the right distance apart for the clips (see sketch).



Cost.—The cost of the material only in the bridge was £1,800, delivered ready for erection at Eyarbakki.

Test under Load.—The bridge was tested in a most barbarous manner, 1,600 men being marched across it to music. Fortunately, no ill-result occurred.

PLATE I.



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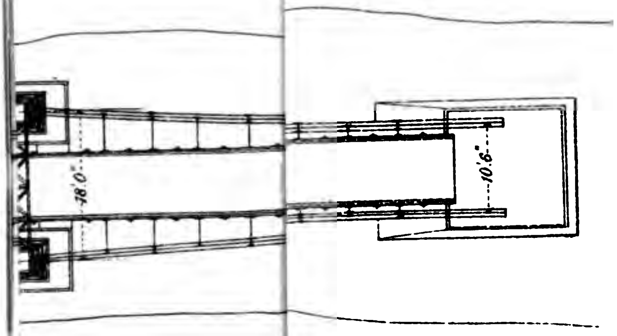

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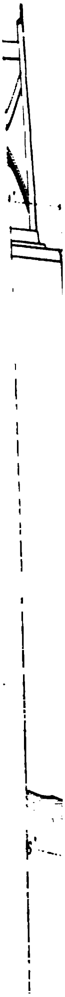
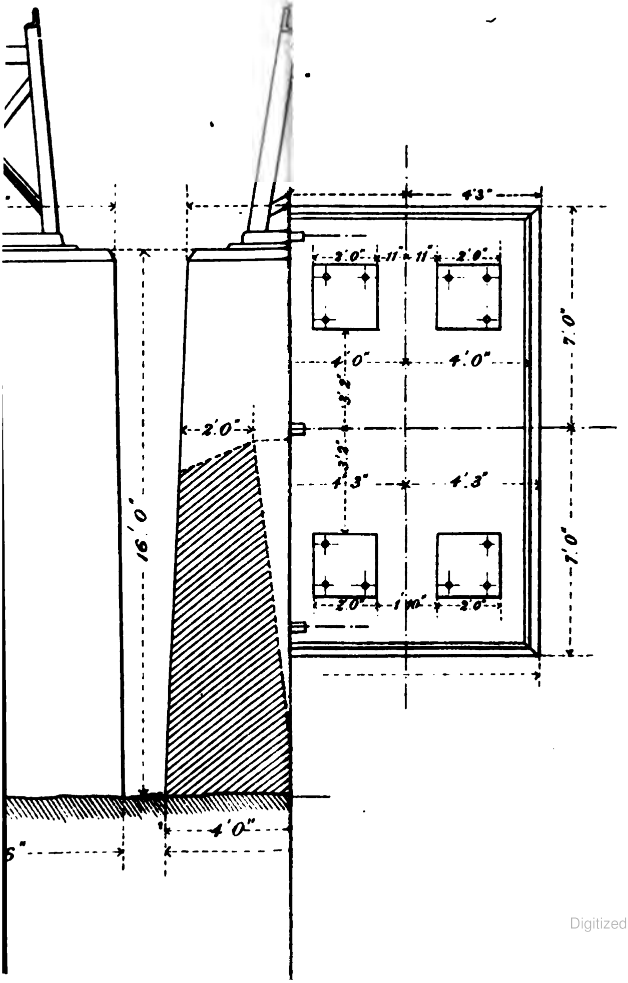


OLVUSA **PLATE II.**

SIDE



BRIDGE. PLATE III.

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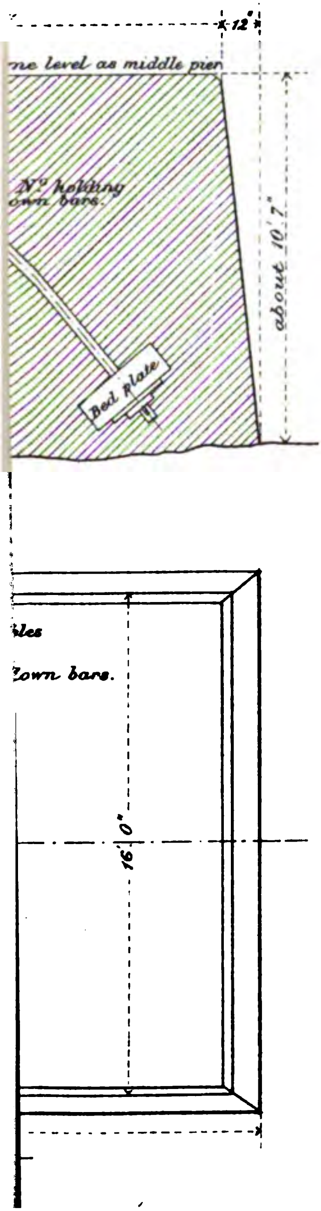

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PLATE IV.

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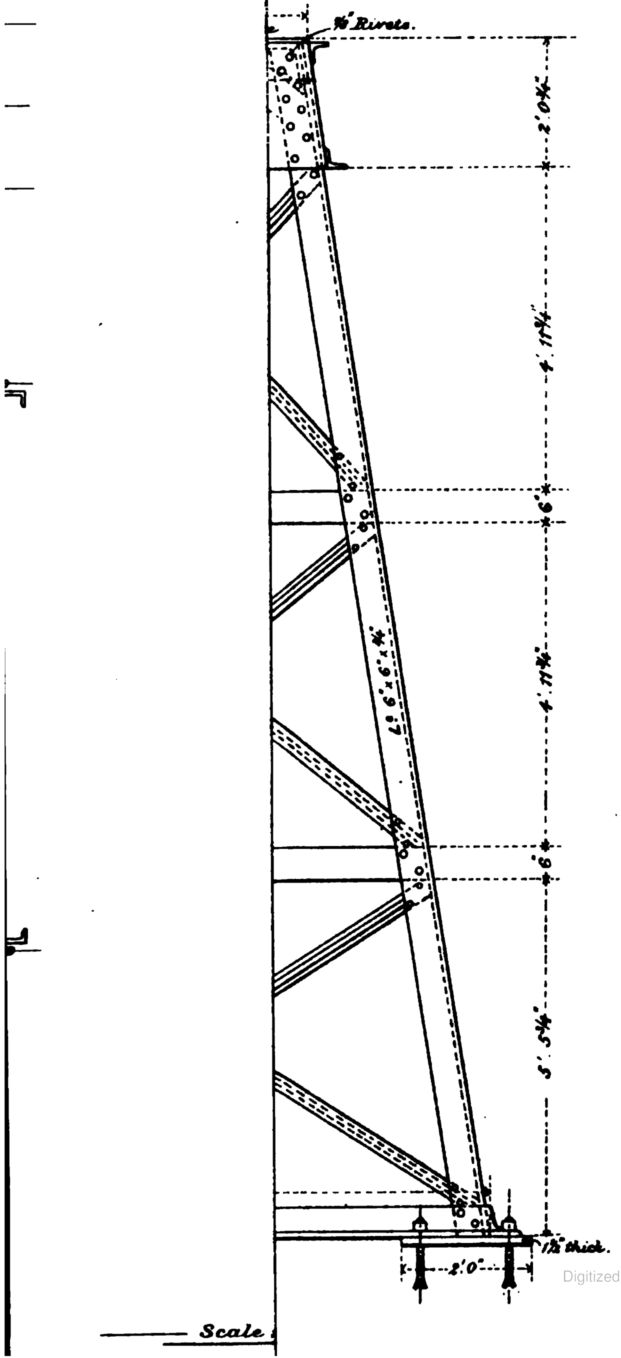

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Fig. 3.

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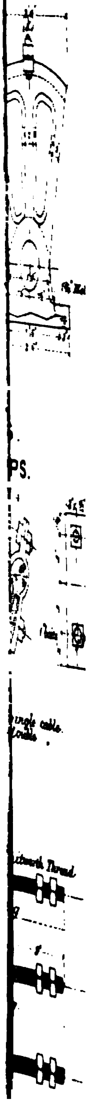

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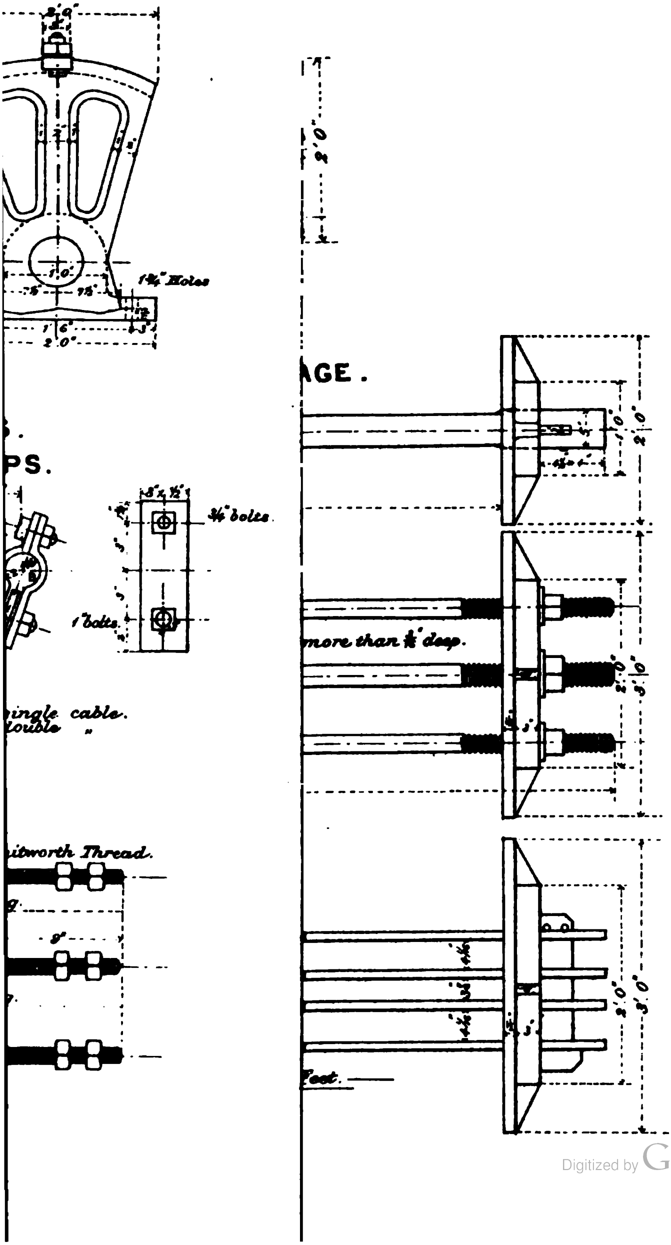
PLATE V.

Fig. 3.

V OF QUADRANT. GIRDERS.



PAPER IV.

A STUDY IN FIELD ENGINEERING: THE BATTLE OF WOERTH.

By the late Captain R. da Costa Porter, R.E.

There are so few opportunities afforded to engineer officers of practising themselves in the work they may be called upon to do on the field of battle that they are reduced almost entirely to theoretical study of this branch of their art. I do not know whether the particular form of exercise of which this paper is an example is one commonly known or used by my brother officers. I have never come across it in any books that I have read, nor have I heard it spoken of. Having used it myself for some time, it has occurred to me that it might be advisable to draw attention to it, as I certainly feel convinced of its value. But in laying it before my brother officers I wish to point out that I do not suppose that the example given possesses any intrinsic value of its own. It is no more a contribution to the literature of military art than a French exercise is an addition to the literature of that language. It is merely intended as a specimen of a practical form of exercise, and in that light alone must it be regarded.

The principles on which it is worked out are as follows:—I take the plot and most detailed account I can obtain of a battle; in this case the battle of Woerth, as described in the German official account of the war of 1870. Adhering closely to the text so far as the incidents of the battle are concerned, I endeavour to follow the movements of the engineer companies of one or more army corps, and having traced their actual performances, I try to draw up a scheme for what they might have done. But in making out this scheme it is necessary as far as possible to make allowances for the difficulties under which men labour during the continuance of an engagement. They do not know at the time all that we know afterwards. Much of the work they would execute must necessarily prove useless, as they cannot foresee the course events will take. To devise a scheme, therefore, which fits the events of the battle as they actually occurred would be useless, as it would be certain to be very unlike anything that would be done in practice. I have endeavoured at each phase of the battle to look at things as they appeared, or would have appeared, at the time. The result, consequently, is very far from being theoretically perfect. I have endeavoured to make my engineers do what, according to my lights, would have been possible and right under the circumstances, as they actually were, but I have not attempted to make them perform work which would be only possible to men who possessed more information as to the course events would take than they had at the time.

Now, in choosing Woerth as an example, I have been guided by the fact that in that battle the work the engineers might have performed would not have had any apparent effect. Beyond, perhaps, saving a few men's lives by the cover they afford, field-works have no influence on the course of a battle, unless they are attacked. Field-works on the field of battle may be divided into two classes:—(1). Those which are intended for the defence of the position taken up in front of the enemy, from which the attacks upon the foe are to start, and upon which they fall back in case of failure. (2). Those constructed to strengthen a captured position. The utility of the former is only demonstrated if the enemy passes to the attack before we are ready to assume the offensive, or in case he makes a counter-attack in force. Similarly, the use of the latter is only shown when the enemy endeavours to re-capture any point we have seized. But though in an uniformly successful action the labour expended in throwing up field-works is lost, the possibility of their proving of value always exists. It is for this reason that I believe that the successful result of the battle of Woerth does not justify the Germans in having made so little use of the spade. For many hours the position of the Vth Corps was a very critical one, and at any moment it might have found itself committed to a struggle for existence against the whole French army. Had MacMahon passed to the attack in the early hours of the morning the absence of field-works might have been severely felt. And yet there was plenty of time during the evening of the 5th August and morning of the 6th to have done much to strengthen the position. It seemed to me, therefore, that in this battle, more, perhaps, than in any other, there was room for adding a hypothetical action on the part of the engineers without interfering in any way with the actual course of events.

In conclusion, I must point out that the quotations in inverted commas are taken from the official account (English translation), and that only these quotations must be regarded as historically correct. They form a framework of truth surrounding the fictitious doings of the engineers.*

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THE BATTLE OF WOERTH.

The victory of Weissenburg on the 4th August, 1870, left the German leaders in complete ignorance of the French movements. They knew that they had defeated only a single division of the enemy; and in the evening they lost all touch even of that small body. Arrangements were, however, made for a forward movement in a southerly direction on the following day, and the corps were to move on the following points:—"To guard the right flank the IInd Bavarian Corps was to advance on the Bitsche road to Lembach, the Vth Army Corps to Preuschdorf, so as to form the advanced guard in the event of the operations being continued to the westward. The XIth Corps was to take up a position at Sulz, Werder's Corps at Aschbach, both facing the south. The Ist Bavarian Corps was to form the general reserve at Ingolsheim. Sulz was expected to be the army headquarters."

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* NOTE BY THE EDITOR.—The reader must clearly bear in mind that in the following paper all the orders stated to be issued to the engineers, or rather pioneers, and all that this handmaiden arm is stated to have done before and during the battle, is fictitious, with the exception of the bridging of the Sauer with extemporized bridges, and any orders given as quotations from the German official account.—EDITOR.

During the day cavalry reconnaissances were pushed out to W., S., and S.W., with the following result:—"On the whole, the observations of the cavalry division established the presence of French troops in considerable force behind the Sauer at Woerth. The situation was not quite clear at Hagenau, because the cavalry had been unable to penetrate as far as that place; nevertheless, it seemed probable that the troops posted there were merely intended to protect the railway." In the march to their respective positions the various army corps also obtained some information. "The IInd Bavarian Corps found traces of the retreat of Douay's Division on the Lembach road." "At Preuschdorf General von Kirchbach (commanding the Vth Corps) learnt that Woerth and the right bank of the Sauer were strongly occupied by the enemy." "The patrols sent out towards this village were fired upon from it; extensive bivouacs could be distinctly seen in rear at Elsasshausen and Froeschwiller."

Everything, therefore, pointed to the necessity for a change of front to the west opposite Woerth, and in consequence "the Crown Prince resolved to concentrate his army more towards the right wing on the 6th August, but in other respects to give them a day's rest." According to the order issued on the evening of the 5th August, the IInd Bavarian and Vth Corps were to remain in their positions, the Ist Bavarian moving up to Lampertsloch. The XIth was to wheel to the right to Hölschloch so as to face westwards, and Werder's Corps was to move upon its left rear to Reimersweiler and face south.

In the meantime the outposts of the Vth Army Corps occupied the heights above the Sauer from Goersdorf to Gunstett, and were in immediate contact with the enemy. On their right lay the advanced posts of the IInd Bavarian Corps, but no enemy was felt directly in their front. On their left rear was the XIth Corps, but here again the Frenchmen were not visible.

The position of General von Kirchbach was, therefore, somewhat peculiar. In front of him was known, or suspected, to lie the bulk of the French army, and should MacMahon proceed to the attack it was on his corps that the first brunt of the fighting must fall. Should the French, on the other hand, decide to accept the combat where they stood, the ground occupied by his outposts must become the position from which the attack would proceed. It was, therefore, evident that every effort should be made to strengthen the line of heights by all possible means. On the other hand, the orders issued on the evening of the 5th showed that the Crown Prince had no intention of advancing to the attack the next day, and that, therefore, unless the French were prepared to assume the offensive, the whole of the 6th and the ensuing night would be available for any works that might appear necessary. Added to this, the fact that the troops had been hotly engaged the day before, and had accomplished a considerable march on that day, induced the General to decide on putting off till the following morning any attempt at the regular preparation of the position. In the meantime, however, he issued orders to the outposts to do what might be possible, while he commissioned the engineers to examine the ground well, decide on the necessary works for the next day, and make their preparations accordingly.

The line of outposts was furnished by the 20th Brigade, which was placed "along the eastern edge of the Sauer Valley, from the Kuhbrücke through Spachbach to Gunstett. Of these, half the 1st Battalion 37th Regiment was at Goersdorf; the 2nd Battalion 50th and 4th Squadron 14th Dragoons at Gunstett. The remainder of the 20th Brigade, with the 3rd Squadron of the same regiment of dragoons, and the 6th Light Battery, was westward of Dieffenbach; the village being occupied by the Fusilier Battalion of the 50th The remainder of the 10th Division, the 9th Division and the Corps Artillery were to the south and east of this village, on both sides of the Sulz road. Mitschdorf and Preuschdorf were each occupied by a battalion from the 10th Division."

During the night the following items of work were performed, but it must be remembered that they did not, at the time, form a portion of a general scheme for the defence of the position, but were constructed rather with a view to the immediate wants of the outposts who made them:—

The half-battalion of the 37th, reinforced by a section of the 3rd Pioneer Company, prepared Goersdorf for defence, barricading the western entrances, preparing the houses on the western front, and arranging the church and the detached cemetery in rear of it as a reduit. Towards morning a line of shelter-trench was also constructed in front of the village, a step was contrived in the road embankment leading to the old mill to serve as a banquette, and a party of pioneers was despatched to mine the bridges at Kuhbrücke and Liebfrauenthal, and to prepare the old mill for defence.

The troops at Dieffenbach took some steps towards putting that village in a state of defence; they occupied and arranged the western border of the Fuchshübel wood, and sent an advanced post into Spachbach, which, however, was too weak to do more than arrange a few of the border houses for defence.

At Gunstett "the stone bridge on the Eberbach road was mined, the mill buildings arranged for defence, and the mill bridge, which had been destroyed by the French, was repaired for infantry." In the early morning some shelter-trenches and gun-pits were formed on the heights north of the village.

In the morning, about 5 a.m., the staff and engineer officers directed to draw up a scheme for the defence of the position sent in a report, of which the following is a condensation:—

(1). The French position appears to be of considerable strength, and to offer great difficulties to a direct attack. On the other hand, the ground our troops will occupy affords great facilities for defence. As the flanks will be supported by the XIth and Ist Bavarian Corps, there is no danger to be feared except from a direct attack.

(2). In view of a frontal attack by the enemy, the following position should be occupied:—Commencing at Goersdorf, it would run along the crest of the hills to Dieffenbach. On the right the old mill and Liebfrauberg would be held as detached posts, on the left the Fuchshübel wood and Spachbach must be strongly held, while Gunstett and the ground about it must be occupied till the arrival of the XIth Corps.

(3). For the defence of this line the artillery position would run along the highest portion of the heights, from whence the whole of the ground as far as and beyond the Sauer will be well under fire. Should a subsequent attack have to be made, however, the artillery must be advanced some 600 or 700 yards down the slopes. It is suggested, therefore, that a line of gun-pits be constructed in the position indicated, for defensive purposes, and that should this evening's orders point to an attack to-morrow, August 7th, a further line of gun-pits may be constructed after sunset nearer the Sauer.

(4). The ground between Goersdorf and Spachbach being very open, shelter-trenches and cover-trenches can only be made use of in exposed situations. These, like the artillery-pits, may be constructed during the morning with a view to defensive operations, and this evening with a view to offensive.

(5). The pivot or supporting points of the line will be as follows:—

(1). The village of Goersdorf.

(2). A redoubt constructed on the summit of the hill marked 780.

(3). The Fuchshübel wood.

(4). Oberdorf, with Spachbach as an advanced post.

(5). Gunstett.

Preparations should be at once made to make these points as strong as possible.

(6). The preparation of Mitschdorf, Preuschdorf, and Dieffenbach may prove useful in case of a retreat.

(7). As the Sauer would have to be crossed before an attack on the enemy's position could be commenced, preparations should be made for bridging it. As the banks are very steep, pontoons could not be used unless ramps of considerable size were formed.* The proximity of the enemy would render this work very dangerous, and, perhaps, impossible, except during the night. The trestle equipment should, however, be brought up, as that may prove more useful. We possess a bridge at Gunstett already, and should the village of Woerth fall into our hands we shall no doubt find another there.

(8). A certain quantity of tools have been found in the villages, and those of the 3rd Company of the Pioneers are at hand. The remainder of the tools of the army corps, including those of the pioneer train, have been left behind at Lampertsloch. They might, however, be brought up by 10 o'clock.

Before this report (which sketched in the merest outline the work proposed to be done during the day, on the supposition that the battle would not take place till the 7th) had reached General von Kirchbach some vigorous skirmishes had taken place between the outposts in front of the Vth Corps. The result of these skirmishes, combined with a curious series of mistakes concerning the Crown Prince's orders, led to the battle being fought on the 6th, and consequently the report became to a great extent useless. It is interesting, however, as showing what measures might have been undertaken had the armies remained in front of each other for 24 hours after (as was intended) it was sent in. It should be remembered, also, that General von Kirchbach had time during the night of the 5th—6th to execute a great portion of the work suggested, and that he did not do so was due to the Crown Prince's army-order, which led him to believe that he would have plenty of time after giving his men a complete night's rest. Had it not been for that order, the General must have felt that his corps would have to support the first brunt of the next day's fighting; and that should the enemy advance to the attack he would require all the assistance that spade-work would afford him to maintain his ground till the arrival of the neighbouring corps.

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* A pencil note on the original manuscript states that the Sauer was such a very narrow stream that pontoons could hardly have been used efficiently Leaping poles would have been more useful !—EDITOR.

The outpost skirmish of which I have spoken occurred chiefly at Woerth and Gunstett. "Major-General von Walther, commanding the 20th Infantry Brigade, while making a reconnaissance in person at 4 a.m., remarked an unusual noise and movement in the enemy's camp, which led him to conclude that the adversary was moving away. In order to be certain on this point the General ordered a reconnaissance in force beyond Woerth. In compliance with this the 6th Light Battery first took up a position to the north of the Woerth road at 7 a.m., and threw 10 shells into the place. Upon this the 2nd Battalion 37th Regiment advanced to the attack in company columns. The 7th Company, moving along the road, found the little town unoccupied; the bridges, however, were destroyed." After throwing a few men across the river (which they had to wade), the presence of the French being thoroughly well established, the action was broken off about half-past eight, and the troops returned to their bivouacs, with the exception of half a company, which remained in the cemetery at Woerth. As a result of this reconnaissance a few pioneers were sent into Woerth to attempt to repair the bridge there, a task in which they were only partially successful, as their bridging equipment had not yet arrived. By removing the flooring of some of the houses, however, they were enabled to repair it for infantry by 10 o'clock. The French not having advanced again to the village, the pioneers, aided by a few men detached from the half-company remaining in the cemetery, attempted to arrange the western face of the village for defence, but owing to the paucity of their numbers, and the instructions which had been given to them not to draw the enemy's fire upon them, they were not able to effect much.

"Simultaneously with these proceedings at Woerth, fighting was rife at Gunstett, in which, however, the French took the initiative. Of the detachment posted at that place, the 5th Company 50th Regiment was pushed forward to the Bruch Mill, the 6th to the southern issue of the village; the remainder in rear of the latter, concealed by the vineyards." "At 5 a.m. a line of skirmishers, followed by two companies of Zouaves, advanced from the opposite side of the Sauer valley towards the Bruch Mill, but they were soon compelled to retire by the fire of the Prussian riflemen." Further demonstrations were made against the post, "and a violent shell and musketry fire was directed against the mill buildings and Gunstett. The mill took fire; the 5th Company, however, did not quit the buildings, and soon extinguished it." At 8 a.m. the 2nd Pioneer Company arrived at this point, bringing with them instructions in accordance with the report sent in by the staff as mentioned above. An attempt was, therefore, made to carry out these instructions, and the preparation of Gunstett and Spachbach was at once undertaken. A party of men was also sent to the heights north of Gunstett to prepare our artillery and infantry position there. The cuttings through which the road from Gunstett to Spachbach ran were arranged for musketry, a line of gun-pits was constructed on the summit of the hill, and materials were collected for throwing foot-bridges over the Sauer. These works were somewhat annoyed by the enemy's fire, but the thin line of workmen suffered but slightly from the shells, most of which failed to explode.*

It is now necessary to turn for a short time to the movements of the IInd Bavarian Corps, for it was owing to these the Vth Corps resumed the offensive a little later. The Bavarians had passed the night at too great a distance from the scene of battle to make their operations of any value for my present purpose, and I shall, therefore, commence my account of their doings from 6 a.m., when the 4th Division was assembled at Mattstall waiting the development of events. It was known that the enemy were yet some distance to the front, and the commander, General von Hartmann, did not expect to have to fight on the ground then occupied. As a matter of precaution, however, he ordered his pioneers to undertake a few defensive arrangements in that village, believing that they might become useful should a subsequent retreat become necessary. He was as yet somewhat ignorant of the course events were likely to take during the day, but he recognized the possibility of the line of heights, across which ran the road to Langensulzbach, becoming the battlefield on which his corps would have to fight. It was further evident that should he have to advance to the attack of Froeschwiller the only available artillery positions must be sought for on those heights, and more especially on the spur north of the old mill.† He, therefore, issued orders that, should an advance take place, the pioneers, aided by such troops as might be left in reserve, were to prepare Langensulzbach for defence, and construct such shelter-trenches and gun-pits on the heights as might be required.

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* "The enemy, however, made no real attack, but rather satisfied himself with keeping up an artillery and musketry fire, which was answered by the Prussian skirmishers, *and caused them but little loss.*"

† A pencil note on the original manuscript states that the trees covering this spur were so high that nothing could be seen from it.—EDITOR.

At about a quarter-past eight the increased noise of the cannonade at Woerth led General von Hartmann to order the advance of the 4th Division in the direction of Froeschwiller. He was in complete ignorance as to the course events were taking in front of the Vth Corps, but he deemed it necessary to make a diversion on the enemy's left flank, lest the whole French army should fall upon and destroy the one German corps in its front.

The advanced guard proceeded, in consequence, to Neehwiller, while the bulk of the 4th Division, crossing at Langensulzbach, wheeled to the south and became hotly engaged with the hostile skirmishers who occupied the roads north of Froeschwiller. During the continuance of the struggle which ensued, most of the reserves, which were at first left at Langensulzbach, were drawn into the front line. At 10.30 the Crown Prince's orders to discontinue the engagements (orders which were in reality meant for the Vth Corps) led General von Hartmann to fall back again. At that time his front extended from the saw mill in a westerly direction, along the edge of the Langensulzbach wald, while Neehwiller was occupied as a detached post on the flank. The spur between the saw mill and the old mill was also occupied, and formed the point on which the retirement took place, the remainder of the line falling back behind Langensulzbach, the movement being completed about 11.30 a.m.

Notwithstanding General von Hartmann's order, very little work was effected on the heights in rear of Langensulzbach, for the reserves, to which had been allotted the task, were very early drawn forward into the shooting line. The following items of work had been commenced :—

(1). At Langensulzbach the bridge had been mined, barricades erected in the western border, and some walls and houses loopholed.

(2). Gun-pits for three batteries had been constructed by the Ist, IInd, and Vth Batteries of the 4th Division on the heights in rear of the village, and those of the Vth Battery were able to direct their fire towards Froeschwiller, though at very long range.

(3). Want of men had prevented any great length of shelter-trench being formed, but the escorts of the batteries had entrenched themselves.

(4). Gun-pits for one battery had been constructed on the spur between the two mills.

(5). The saw mill was arranged for defence. The old mill had been prepared during the night by the outposts of the Vth Corps.

In addition to this, the advanced guard had commenced the preparation of Neehwiller, before it was recalled.

"We must now depict the proceedings of the Vth and XIth Corps. The Chief of the Staff of the Vth Corps, Colonel von der Esch, had proceeded to the advanced guard in consequence of the vigorous firing at Woerth." His intention at that time was to order the discontinuance of the action, and to arrange for the immediate execution of the defensive plans drawn up by the Staff. "When he arrived there, after half-past 8 o'clock, the reconnoitring action had been broken off. On the other hand, at this time, from the position on the heights east of Woerth, the firing from the direction of Langensulzbach was observed to be increasing in intensity, as well as the development of an action at Gunstett. Under these circumstances Colonel von der Esch, with the concurrence of the commander of the advanced guard, considered it imperative to resume the struggle at Woerth, so as to prevent the enemy from turning with his whole force against *one* wing of the German army." Thus the same reasoning that led the Bavarians to advance beyond Langensulzbach now induced the Vth Corps to re-commence the action, and, as will be hereafter seen, this renewed activity at Woerth again caused the Bavarians to advance.

Although a definite offensive movement had now been determined on, Colonel von der Esch did not entirely give up the idea of fortifying the position from a defensive point of view; still, it became necessary to modify some of the details contained in the scheme. The object with which the new advance was undertaken was rather to make a demonstration against the enemy's front, so as to draw his attention away from the Bavarians, than to attack his position seriously. It was hoped, therefore, that the 20th Brigade, which formed the advance guard, would furnish sufficient infantry for the purpose, while a due importance would be given to the demonstration by deploying the whole of the Corps Artillery. In order to be prepared for emergencies, the main body of the corps was ordered up to Dieffenbach, and consequently the 9th Division and 19th Brigade were formed up there by 10 a.m.

The modifications made by Colonel von der Esch in the defensive scheme were chiefly the omission of the redoubt, for the construction of which there would not now be time, and the creation of the advanced line of gun-pits now instead of in the evening. The preparations necessary for the approaching passage of the Sauer were pushed on, and two engineer officers were sent forward to examine the stream and report upon the most suitable points for effecting this. The construction of the advanced line of gun-pits for 84 guns was proceeded with, the guns in the meantime occupying a slightly advanced position. For this purpose there were available the escorts of the batteries and one-half of the 1st Pioneer Company. These supplied five men and one sapper to each gun-pit, or 420 infantry soldiers and 84 sappers in all. The gunners were unable to assist in the work, as they came into action almost as soon as they came up.

After 10 o'clock other portions of the 9th Division were employed on the following works, and remained so employed till 1 o'clock :—

(1). The preparation of Goersdorf was continued, and a shelter-trench constructed along the road leading to the house at Liebfrauberg, this latter being also put in a state of defence.

(2). Shelter-trenches were constructed connecting Goersdorf with the right of the line of guns, the trenches making a bend outwards round the hill near Goersdorf.

(3). A second line of shelter-trenches was constructed between Goersdorf and Dieffenbach, gun-pits being also formed along this line.

(4). The preparation of Dieffenbach was continued.

(5). The border of the Fuchshübel wood was prepared for defence, and part of the narrow tongue of trees running to the Sauer was cleared away.

(6). Shelter-trenches were constructed connecting the left flank of the line of guns with Spachbach, the preparation of that village being also continued.

While these defensive arrangements were being undertaken some of the pioneers were employed in preparing for the passage of the Sauer. It was discovered that the baulks of the bridge equipment would be long enough to reach from bank to bank, and messengers were, therefore, sent to the rear to hurry up the light pontoon train. It was found impossible to bring this up in time, and as a temporary expedient a quantity of hop-poles were collected from the adjacent fields. These were tied together in bundles and placed across the stream, thus forming a rough foot-bridge, subsequently used by the infantry, who also waded through the stream at many points, although the water was breast high.

The fire of the long line of artillery having soon reduced the

French guns to silence, "General von Kirchbach gave orders, soon after 10 o'clock, for the advanced guard to re-occupy Woerth and to advance to the heights beyond." The attack was made in two columns, "2¼ battalions of the Fusilier Regiment crossing the Sauer at Woerth, and two battalions of the 50th at Spachbach."

It will be remembered that after the failure of the first advance the town of Woerth had been evacuated except by two companies of fusiliers and a party of pioneers. These had made preparations for the repair of the bridge, and the advance of the troops was now facilitated by this precaution. Debouching beyond Woerth, the line of hills was soon gained, but after a sanguinary combat the men were driven back upon Woerth, the western border of which was occupied and arranged for defence. Further to the south the two battalions of the 50th were equally unable to maintain themselves upon the heights, but, occupying the ditches upon the Woerth-Morsbronn road, they held their ground on the right bank of the river. The whole of the advanced guard was, therefore, employed in retaining possession of the narrow strip of ground they had seized beyond the Sauer; and if they were successful in maintaining their positions, they were at least as unsuccessful in all attempts to push beyond it. At Woerth more than one attempt was made to gain ground, always fruitlessly; and more than once the French advanced to seize the town, but never successfully. With the exception of loopholing a few houses in Woerth, there was no possibility of executing any work; the men's energies were fully employed in repelling the enemy's vigorous counter-strokes. Happily these counter-strokes were never made in great force; no organized attempt was made to drive the Germans across the Sauer, and the enemy's offensive movements were confined to the temporary advance of a company or a battalion when an opportunity seemed to present itself. Affairs remained in this state till 12.30, about two hours after the first advance was sounded, and one hour after the failure of the attack.

At that hour a fresh change took place in the character of the attack made by the Vth Corps, but as that change was due to the action of the XIth and Bavarian Corps, it is necessary now to enquire into their movements.

The XIth Corps, under the command of Lieutenant-General von Bose, had bivouacked on the night of the 5th near Sulz. According to the orders received from the Crown Prince, General von Bose intended wheeling to his right and bivouacking at Hölschloch, pushing forward the 41st Brigade, accompanied by two squadrons of the 14th Hussars and two batteries of artillery, towards the Sauer. This advanced guard was to occupy the forest lying in front of Hölschloch and the ground in front of it, connecting with the left flank of the Vth Army Corps at Gunstett, and orders were issued to it to prepare defensively the ground occupied. The following points were brought to the notice of Colonel Koblinski, commanding the advanced guard, to guide him in carrying out these orders:—

(1). The Vth Army Corps occupies a position in proximity to the enemy, with its left flank resting on Gunstett. An advance of the enemy from Morsbronn and Durrenbach might threaten this flank, and consequently a position should be prepared facing south, and connecting Gunstett with the Hölschloch wood.

(2). As no offensive movement is intended for this day, there will be ample time to carry out such works as may be necessary.

(3). As the position of the Vth Corps is somewhat extended, it is likely that the occupation of Gunstett may be handed over entirely to the XIth Corps.

The engineer staff had examined the ground during the night and drawn up the following report:—

(1). The general line of the position will be along the Gunstett-Hölschloch road; the right resting on Gunstett, the left extending to the east border of the Hölschloch wood.

(2). The preparation of Gunstett and the heights north of it has been commenced by the outposts of the Vth Corps; it will be only necessary to complete their arrangements.

(3). Excellent artillery positions exist to the north of the main road, from which the passages over the Sauer and Bieberbach can be thoroughly commanded. A line of gun-pits may be constructed there.

(4). A line of shelter-trench may be formed near the foot of the hills, along the lower road, a second line being formed along the upper road.

(5). Gunstett lends itself well for defence. The Sauer forms a wet ditch round it, completely under the musketry fire of the defenders. The houses are well built and afford facilities for flank defence. The western face is flanked by a triangular projection of the village and by the road embankment. The southern face is the narrowest, and at this point there are some large mill buildings forming a strong *point d'appui.* Two roads crossing the Bieberbach and Sauer by small stone bridges are swept by the fire of this mill.

The eastern face is well flanked by the houses along the Hölschloch road.

(6). It will be necessary to occupy the southern border of the Hölschloch wood defensively, and as the trees are mostly young and of small girth, it may be found possible to form an abattis. The eastern and western borders may also be prepared defensively.

(7). Should the enemy attempt to neglect the village and wood and to advance between them, he will be under the effective infantry fire of one or other of them, for they are but 2,000 yards apart. As a wooded watercourse, however, exists midway between them, special precautions must be taken at this point. Should time admit, the wooding may be cleared away, and gun-pits for at least one battery should be made firing straight down the watercourse.

(8). The occupation and preparation of Biblisheim might be advantageous, as it would enable patrols to search the Oberstrieton wood. Should the offensive be hereafter assumed, this point would become of importance on account of the bridge at that point.

With this information at his command, Colonel von Koblinski commenced his march at 5.30 a.m., followed at 6 a.m. by the remainder of the 21st Division.

"About 7 a.m., while on the march, the sound of guns was audible in the direction of Woerth, but as it again ceased the men moved into the bivouacs previously indicated, and commenced to take up their quarters and place outposts." In the meantime the advanced guard, "emerging from the wood, saw a French camp on the heights beyond Gunstett, and at the same time the cannonade at Woerth increased in intensity."

In consequence of this, Lieutenant-General von Schachtmeyer, commanding the division, "at once ordered the 3rd Battalion of the 80th Regiment to advance to the support of the troops of the Vth Army Corps at Gunstett, while the rest of the infantry of the advanced guard formed up at the western issue of the wood."

The precipitate action of the 20th Brigade of the Vth Army Corps had, therefore, completely altered the ideas of the leaders of the XIth Corps, and made it appear necessary to prepare for an immediate engagement, rather than to take precautions for a prolonged period of rest. The first action taken under these new ideas was more of a negative than of a positive character. The defensive scheme was for the present put on one side, and while one battalion of the advanced guard was allowed to proceed to its destination at

Gunstett, the remainder of the brigade was retained in hand waiting for eventualities.

"At 8 o'clock a hostile battery appeared on the heights beyond the Sauer; at the same time a battalion was seen descending the slopes to attack Gunstett."

This fact, combined with the sound of an engagement at Woerth, induced the General of the division to believe that the French had advanced to the attack. Knowing that the Vth Corps was exposed to the entire strength of the enemy's army, it was deemed far better to hurry to the assistance of General von Kirchbach rather than to spend the time in constructing works which might have to be evacuated as soon as finished.

"The advanced guard, therefore, received orders to follow the battalion which had already preceded them in this direction, with a view to defending the eastern bank of the Sauer." The divisional artillery was also brought forward, and posted on the heights north of Gunstett, at which point they found gun-pits already made for them by the pioneers and outposts of the Vth Corps (see above). Orders were, in addition, sent to the remainder of the division to support the advance, and at 9 a.m. the troops were arranged as follows:—

One and a-half battalions of the 87th Regiment, with a battalion of the 80th in support, were at Oberdorf, one battalion of the 80th was acting as escort to the guns on the heights above Gunstett. The remainder of the two regiments, consisting of two and a-half battalions, were in the village. Of the remainder of the division, the 11th Rifles had advanced to Gunstett, while the 42nd Brigade was massed at the western border of the Hölschloch wood.

It should be remembered that as yet there was no intention of commencing an offensive battle, and that the arrangements just described had been made with the view of supporting the Vth Corps against what appeared to be the commencement of a general attack of the French. Though the necessities of the situation had induced General von Schachtmeyer to push forward his whole advanced guard into Gunstett, he still intended to carry out the general idea of occupying a position, facing south, between Gunstett and Hölschloch. He, therefore, ordered the 42nd Brigade to undertake the construction of the defensive works indicated in the engineers' report. As matters appeared, however, to be in a somewhat critical state, he ordered that the brigade should be kept in hand as far as possible, and that the work should be commenced by the two companies of pioneers that accompanied the division, aided by the smallest working parties that could be deemed sufficient.

These orders were never carried out, for within an hour the brigade was called into the first line. The advanced guard had attempted to cross the Sauer, and after a sanguinary struggle had been driven back, and the aspect of affairs was so threatening that General von Bose, who now appeared upon the scene, was forced to order up the 22nd Division from Sarburg, and to bring the 42nd Brigade to the aid of the 41st. Shortly after a message arrived from General von Kirchbach praying for energetic co-operation in an attack upon the enemy, and from this moment all idea of fortifying the Gunstett-Hölschloch position was abandoned. Instead of remaining on the defensive behind the Sauer, General von Bose now determined to commit his corps to a determined attack on the enemy's position, trusting to the advance of Werder's corps for support in case of defeat.

"In the manner just detailed were the three corps of the IIIrd Army in first line committed in greater or less force to an engagement, during the course of which advantages which had been derived had either to be again yielded, owing to heavy losses, or were maintained only with great difficulty against the vigorous on-laughts of the French. General von Kirchbach felt compelled to take the responsibility upon himself of a very momentous decision."

Notwithstanding the Crown Prince's reiterated commands that no offensive battle should be commenced on that day, the force of circumstances had greatly compromised the advanced guards of three army corps. To withdraw now would be very difficult, but even if it proved possible, it would yield the enemy the moral advantage of a victory. "General von Kirchbach, therefore, ordered his corps to make a fresh advance; he reported to this effect to the Commander-in-Chief, and requested the neighbouring corps to lend their co-operation."

The first measures ordered by General von Kirchbach in order to carry out his new intentions included the reinforcement of the front line by the 19th Brigade, and the advance of the 9th Division nearer to the front. In consequence of these orders all organized work on the defensive position ceased at noon, or two hours after it had been commenced, and the battle finally assumed an offensive phase.

By 1 o'clock the 9th Division had been called into the front line, the 17th Brigade on the right at Woerth, the 18th on the left at

Spachbach, and from this time no *formed* bodies of reserves were left on the eastern bank of the Sauer. At the same time, however, it was found impossible to bring the whole of these fresh troops into line. "The advance of the 17th Brigade through Woerth met with frequent obstructions. The bridges had been repeatedly damaged, the roads were encumbered with troops, wounded men, and frightened townspeople; the bursting of shells increased the confusion." For these reasons two battalions of the 58th alone succeeded in passing through the town, the remaining battalion of that regiment, together with the 2nd Battalion of the 59th (the two other battalions of which had gone to Goersdorf), remained at the cemetery. These, with the 2nd Battalion of the 6th Regiment, belonging to the 19th Brigade, formed a temporary reserve, the only available one of the army corps. Though practically forming a reserve, these three battalions could not execute any defensive works. Their present position was due to accident, and their commanders intended moving forward at the earliest opportunity. This opportunity soon arrived. "A favourable moment was chosen about 2 p.m., when a fresh forward movement of the French upon Woerth had been repulsed with great slaughter." A determined attack was, therefore, made upon the heights in front, the edge of which was gained and occupied by dense bodies of skirmishers; but all further advance failed for the time being. The level ground on the summit of the heights was swept by the close fire of the enemy's infantry, and the men could not maintain themselves on it. Seeking shelter below the crest of the hill, the skirmishers were equally able to prevent any advance of the enemy, and for a time the action came to a standstill. On the left two half-moon shaped breastworks had been captured, and these now proved of advantage to the assailant. Placed *on* the plateau, their defenders had not been able to sweep the ground in front of them, and consequently the German skirmishers had been able to advance to their capture with comparatively small loss. Once in their possession, the parapets afforded a very efficient cover to the men, and being placed *on* the plateau, the men lining them were able to keep up an effective fire on the retreating French.

By 2.45 p.m. the crest of the hills was everywhere in the possession of the German troops, but the entire energies of the men were taken up in maintaining their positions, and no further advance would be attempted for the present. There was no possible opportunity for the employment of the spade in forming shelter for the men in their exposed position, for the struggle was of far too hot a nature to make it possible for the men to work. Here and there a rough breastwork was hastily formed by piling a few logs that lay ready cut upon the ground, but such cover as was used was sought for on the banks and ditches, and other existing features of the ground.

Of the three companies of pioneers present with the army corps, one repaired the bridge of Woerth to make it available for artillery, and at half-past two advanced to the front line to be ready for emergencies. Of the other two, one had prepared several foot-bridges over the Sauer, and then, entering Woerth, had endeavoured to perfect the defensive arrangements in that place. The other, at Goersdorf, had continued the preparation of that place, and subsequently took part in the movements of the Bavarian Corps, which, however, will not be entered into in detail for want of space.

We will now turn once more to the proceedings of the XIth Corps, which "we left at the point where the 41st Brigade was pressed back to the eastern bank of the Sauer, and the 22nd Division had received orders to advance against the enemy's right flank." This movement had completely altered the ideas under which the corps had up to this moment been acting. It was no longer a question of fortifying a position facing south on the line Gunstett-Hölschloch. The corps was to advance on Gunstett with the object of crossing the Sauer, and if any defensive works were to be constructed, they would be on the Gunstett-Biblisheim direction. At this time the 1st Pioneer Company was in Gunstett with the portion of the 21st Division at that place, and as the village might possibly become the key of the whole left flank of the position should the French assume the offensive, the entire energy of the company was directed to preparing it for defence. The proceedings of this company need not, therefore, be further alluded to. The 22nd Division in its advance broke up into two columns, the 43rd Brigade advancing towards Durrenbach, the 44th towards Gunstett and Spachbach. The 3rd Pioneer Company accompanied the former, the 2nd the latter. The 1st Pioneer Company having been directed to remain at Gunstett, the 2nd Pioneer Company was ordered to divide itself into two sections, one to accompany the advance from Spachbach, the other that from Gunstett.

The immediate plan of the German commander now consisted in attacking the Niederwald and the Albrechtshaüserhof in front from Spachbach and Gunstett, while the left column, crossing the Sauer between Gunstett and Biblisheim, should attempt to turn the French right at Morsbronn. We will now take in succession the three bodies of engineers, viz., the two halves of the 2nd Company and the 3rd Company, and endeavour to realize their position.

Half 2nd Pioneer Corps at Spachbach.—The Sauer in the immediate front would have to be crossed at the commencement of the attack, and for this purpose, in the absence of bridging material, it was necessary to collect such planks and other timbers as could be found in the village wherewith to construct foot-bridges. When the infantry were crossing the open ground beyond, there would be nothing for the engineers to do, but when the Niederwald was reached it was at least possible that the presence of a number of cutting tools, and trained men to use them, would be found useful. Besides, there would be but little risk then in crossing the open ground in rear of the infantry. What might be required could not be seen owing to the wood, but it was determined not to take any further tools forward at once, but to leave them with a small party in the village. Some guncotton and fuzes, however, were also carried.

Half 2nd Pioneer Company at Gunstett.—Same preparations for crossing the Sauer. Here also the engineers were to remain behind until the infantry had crossed the open space to the Hagenau road. The well-built Albrechtshaüserhof would evidently have to be captured; for this purpose some guncotton might prove useful. The building would then have to be prepared for defence, and crowbars, chisels, etc., would be wanted. Entrenching tools were also likely to prove useful at this point, and it was, therefore, arranged that as soon as the building had been captured, an officer (left behind for the purpose) should bring them forward.

3rd Pioneer Company.—Two streams would have to be crossed in this case, the former by an existing bridge. As there was but little or no opposition to the advance of the left column, there was but little difficulty in effecting the passage of the second and smaller one. It was possible, however, that a prolonged village fight would take place at Morsbronn, and guncotton, crowbars, etc., might be required, while the village would subsequently have to be put into a state of defence.

At 12 o'clock the three attacks were commenced, nearly simultaneously. The right column succeeded in penetrating the Niederwald, and, wheeling to the right, occupied the northern border, where they were checked at about 12.45 p.m. Though the fight was somewhat stationary here for more than an hour, it was of too hot a nature to permit of any work being done, and the engineers were kept back under cover of the wood.

The second column advanced to the attack of the Albrechtshaüserhof, but though the defence was obstinate, it partook entirely of the nature of a free fight. Until, therefore, the building caught fire and was evacuated by the French, no work was found for the engineers to do. Then, however, they at once advanced to the building, and having extinguished the flames, arranged the ruins for defence, creating a small defensive position around it in case the assault on the wood in front should fail.

In the meantime " the village of Morsbronn, which was but weakly occupied, was captured at the first rush. Having, by the capture of the positions of Morsbronn and Albrechtshaüserhof, won the first points of support on the western bank of the Sauer, the next question was the combined advance against the Niederwald." "To carry this into effect, the Prussian troops at Morsbronn must wheel to the right and move in a north-westerly direction." It was then determined to leave half the Pioneer company at Morsbronn, to place it in a state of defence, while the other half should advance to the hill marked 756 in the map as soon as it had been crowned by the infantry, and there commence gun-pits for an artillery position to aid in the assault on the Niederwald. Before, however, these arrangements could be carried out, a furious charge of Michel's brigade of cuirassiers took place. The 3rd Pioneer Corps happened at that time (apparently without any definite reason) to be in the front line on the left, and it took a part in resisting the attack.

The left column now advanced and joined the left wing of the troops at Albrechtshaüserhof, who were now advancing again after a temporary repulse, during which the buildings placed in a state of defence (as already described) had alone been held. These buildings checked the French counter-stroke, and materially assisted the Germans in regaining the lost ground. About this time also the French evacuated Eberbach, which was occupied by some of the troops from Morsbronn.

"The right wing of the French having thus been thrown back into the Niederwald, the next point for consideration was the Crown Prince's instructions, which had meanwhile arrived, for a further advance upon the hostile positions at Elsasshausen* and Froeschwiller, in concert as much as possible with the attack of the Vth Army Corps in front. In order to secure its success, General von Bose did not hesitate to employ his whole force, and, therefore, gave orders to bring up the artillery and the three battalions in reserve at Gunstett." These troops crossed the river, and following the Woerth road east of the Niederwald, advanced to the ravine beyond it leading to Elsasshausen. In the meantime the two columns between Eberbach and Albrechtshaüserhof entered the Niederwald, and succeeded in reaching the further edge. It will be noticed, therefore, that the gun-pits constructed on the hill marked 756 facing the Niederwald were neither used nor required.

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* A pencil note on the original manuscript states that Elsasshausen consisted of only 13 or 14 wattle and daub cottages.—EDITOR.

There were now with the advancing troops only the two halves of the 2nd Pioneer Corps, the remainder of the engineers being employed in rear on work which might have proved useful in case of a reverse, but which, under the actual circumstances of the case, were without value.

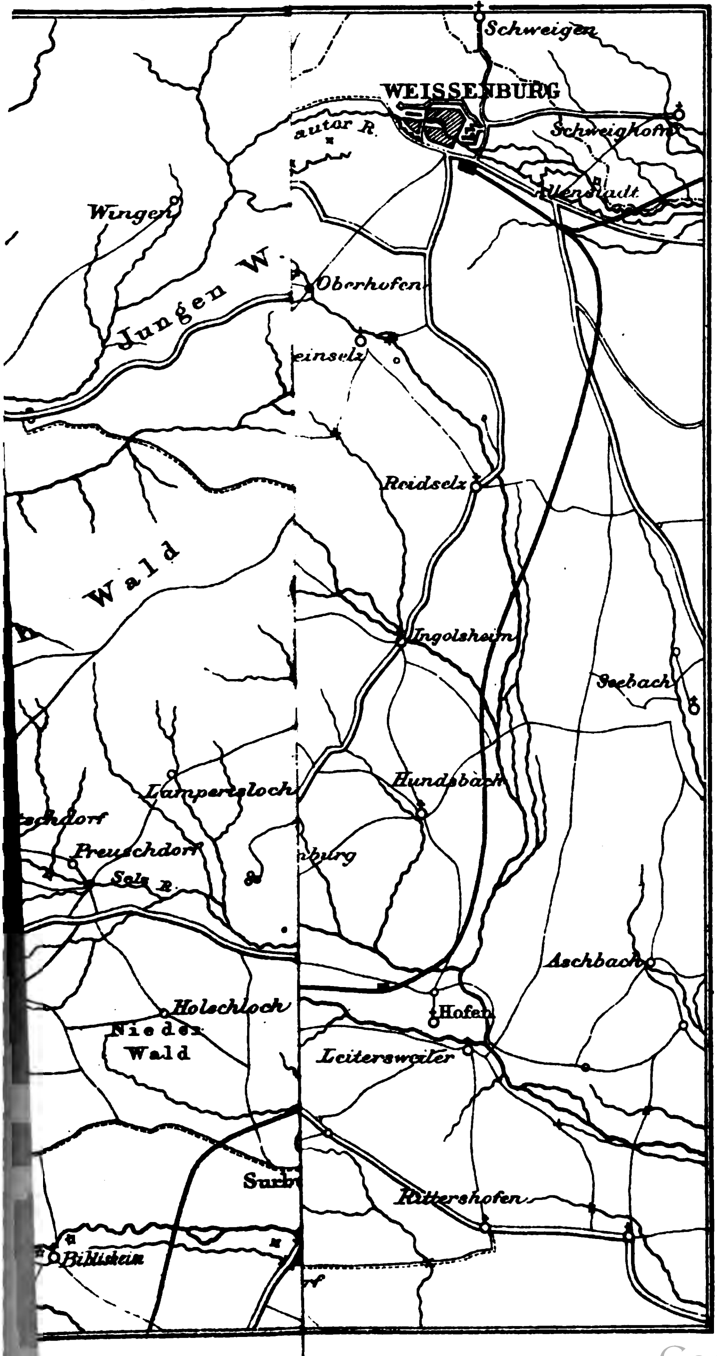
"The result of these successes was to force back the right wing of the French army to Elsasshausen; we were now immediately in front of the enemy's position at that point. It was strongly occupied; several batteries were posted on the heights westward of the village, and in rear of it strong reserves were visible." "Despite the withering fire of the French, the open space between the wood and the village was traversed." A short but sharp struggle ensued, and the village was captured, the left wing of the Vth Corps assisting in the assault.

There was now again a pause in the struggle while preparations were made for the final crisis. "The front of the new position ran in general along the road from Elsasshausen to Gundershoffen." It was absolutely impossible to get any work done in the open, owing to the heavy fire of the enemy, but the village itself was placed in a state of defence. Even this work was seriously incommoded by two counter-attacks delivered by the French during the hour that preceded the capture of the village. And now, about 3 p.m., the final blow was to be struck.

Want of space compels me to omit any mention of the operations of the Wurtemburg Division and the Bavarian Corps. Suffice it to say these had now all come into play, and the circle round Froeschwiller was becoming narrower and tighter. I must return, however, for a brief space to the Vth Corps, which we left clinging desperately to the edge of the plateau on which Froeschwiller stands. With the advance there was one company of pioneers. The company lost very severely during the forward movement, and this loss was not compensated for by any opportunity of doing useful work before the final attack took place. It may be doubted, therefore, whether it would not have been wiser for it to have remained at Woerth ready to advance when required, which would only have been when Froeschwiller was occupied. At the same time, it must be remembered that the complaint usually brought against engineers is that they never are at the front when required, and to ensure their presence when wanted it may sometimes be necessary to expose the men in an apparently useless manner. Besides, engineers are soldiers, and they may frequently be of great value as such.

About 4 p.m. Froeschwiller was stormed and captured. "The French maintained for some time a short but hopeless street fight in the village," during which the pioneer company of the Vth Corps was of use in forming gaps in walls and other obstacles, blowing in the partitions of houses, etc. Similarly, the pioneers of the XIth Corps found work in opening paths through the gardens south of the village, by which the reinforcements could enter.

TLE OF WC PLATE I.



PAPER V.

SEWAGE PURIFICATION.

BY CHARLES H. BELOE, M. INST. C.E.

SINCE the delivery of the lecture in 1888 on the purification of water and sewage by the magnetic spongy carbon process very considerable improvements have been effected in the purification of sewage.

No important change has been made in the materials used by the International Company for the treatment of sewage, but the methods adopted in applying them, and in the construction of sewage works generally, have undergone so many and such important alterations that it has been deemed advisable to prepare this lecture in order that the officers of the Royal Engineers may become acquainted with what is admitted to be the most improved mode of dealing with this important question.

It is not proposed to deal with the subject of the purification of water in detail, as, with the exception of a modification in the distribution of the materials in the filter-bed, and the adoption of polarite chambers, which will be described hereafter, no alteration has been made in dealing with water from that described in the previous lecture on this subject.

Neither is it intended in this lecture to recapitulate in detail the descriptions of the various processes which have been tried for the purification of sewage, and have been more or less failures, or to repeat the arguments used on the previous occasion against broad irrigation or intermittent downward filtration.

For information on these points reference must be made to Vol. XIV., Paper VIII., 1888, of the *Professional Papers of the Corps of Royal Engineers.*

The author can only add that the additional experience gained by him during the past seven years has not caused him to alter in the slightest degree any one of the opinions expressed by him in the former lecture, but, on the contrary, all the arguments used then against the treatment of sewage by land have been strengthened and confirmed by the additional observations made by him on the results obtained by sewage farms. He is firmly of opinion that the most efficacious method of purifying sewage, in the great majority of cases, that is known at the present time, is by treating the sewage with suitable chemicals in properly designed tanks, and filtering the tank effluent in artificial filter-beds containing some material possessing a high oxidizing power.

Since the previous lecture was delivered some new processes have been brought before the public, the principal of these being the "Webster Electrical" process, which attracted a great deal of attention, no doubt partly owing to the prevailing opinion that almost everything will be effected by the use of electricity.

Experimental works were erected at Crossness in 1889 to deal with the Metropolitan sewage, and at Salford in 1890 to satisfy the Corporation of that town that the sewage could be dealt with in a satisfactory manner by the electrical process before turning it into the Manchester Ship Canal.

The sewage is made to flow through what is called an electric shoot or channel, divided into cells containing iron plates, to which the electric current is applied. By the action of the electric current the sewage is decomposed and purified.

Mr. Dibdin, the Chemist to the Metropolitan Board of Works, calculated from the experiments at Crossness that the process is capable of removing practically the whole of the matter in suspension, and an average of 22 per cent. of the oxidizable organic matters in solution, at a cost £1 15s. 0d. per million gallons of sewage, exclusive of labour, interest on capital, wear and tear, etc., and the cost of disposing of the sludge.

The consumption of iron is also a serious item. About 3 grains per gallon are said to be used, corresponding to 37½cwts. for 10,000,000 gallons. For a daily flow of this amount the quantity of iron consumed annually would be 684 tons, which at £4 a ton would represent £2,736 per annum, to which must be added the cost of removing and replacing the plates, which could not be used up to the last pound.

At both the above-mentioned places fairly satisfactory effluents were obtained, but the process was not adopted at either, presumably on account of its excessive cost, both of installation and of the heavy working expenses.

The "Amines" process was introduced at Wimbledon, and great things were expected from it.

It consists of adding a small quantity of herring brine and a large quantity of lime to the crude sewage before it enters the precipitation tanks.

The "Hermite" process has been tried experimentally at Worthing, and is about to be adopted at Ipswich. It consists of applying an electric current to sea water, by which means the water undergoes electrolytic decomposition, and in the end becomes surcharged with oxide of chlorine, which is well known to be a powerful disinfectant and deodorant. This electrolyzed solution is added to the sewage in the sewers, and it is claimed that it will reach the outfall in a perfectly inoffensive condition.

The works at Worthing were purely experimental, and the machinery employed much too powerful for the quantity of sewage treated.

The works at Ipswich not being completed, no reliable information can be obtained either as to the cost of, or the results obtained by, this process.

It can hardly be called a sewage purification process, any more than the addition of a quantity of Condy's fluid to the sewage in the sewers could be so called.

The "Scott-Moncrieff" system for the bacteriological purification of sewage consists essentially in passing the sewage upwards through a filtering medium 14 inches in depth, and composed of successive layers of flint, coke, and gravel.

This system depends upon the well-recognized truths :—

1. "That bacteria under favourable conditions are capable of indefinite multiplication.

2. "That bacteria exist in sewage which are capable of peptonizing solid organic matter, or, in other words, of preparing it, by a process comparable to that of digestion, for its final disintegration.

3. "That in nature the purification of the refuse of the organic

world is effected by the life-history of these or similar micro-organisms."

This process is practically upward filtration, without æration, or, in other words, putrefaction.

"In order to still further improve the quality of the effluent by longitudinal filtration, by oxidation, and by the action of micro-organisms, Mr. Scott-Moncrieff devised what he has termed nitrifying channels. These in their simplest form consist of half-channel pipes joined together with cement and filled with coke." These channels were originally 30 feet in length, but subsequently they were increased to 80 feet.

For a household of 10 to 12 persons, the filter-bed was 10 feet long by 2½ feet wide, or 25 square feet in area, whilst the so-called nitrifying channel super-added to this was 80 feet in length (the diameter of these channels is not given). For a population of 1,000 persons, therefore, a filter-bed upwards of 2,000 feet square, and a nitrifying channel between 6,000 and 7,000 feet in length, would be necessary.

These bacteriological filters have been tried at Towcester and Aylesbury, and have been discontinued at both places. Nevertheless, it is an established fact that a perfectly new filter-bed, or even an old one recently washed, does not produce as good an effluent as that obtained from an old filter, and some authorities advocate that water should not be used until colonies of bacteria are formed in the filter.

There can be no doubt of the action of bacteria upon water, and that it is most undesirable to disturb the lower layers of filter, and also, if possible, to allow time for bacteria to establish themselves in the top layer of sand after it has been renewed or washed before putting the filter into use, but, unfortunately, the exigencies of the case seldom permit this theory to be carried into effect.

Lowcock's filter for the treatment of sewage is constructed on the principle of ærating the materials in the filter by forcing air into the body of the filter through perforated pipes, the necessary air pressure being obtained by mechanical means. This principle is the correct one, but it is doubtful whether the small amount of pressure required for this purpose necessitates the employment of compressed air.

The experiments of the Massachusetts Board of Health, as set forth in their report of 1891, show that "any treatment which keeps all particles of sewage distributed over the surface of sand particles in contact with an excess of air for a sufficient time is sure to give a well oxidized effluent, and the power of any material to purify sewage depends almost entirely upon its ability to hold the sewage in contact with air. It must hold both sewage and air in sufficient amounts."

In a paper read before the Institution of Civil Engineers (Vol. CXV., p. 299), Mr. Lowcock gives the following conclusions, which the author cordially endorses:—

1. "That filtration is not only a mechanical, but also a chemical and biological process, when it is properly carried out, and when sufficient æration is provided for.

2. "That no practical chemical process yet devised will, alone, do more than remove the suspended matter in sewage, and a very small portion of the dissolved impurities.

3. "That dissolved impurities can only be removed by the action of micro-organisms, *i.e.*, by nitrification; and this can only be effected subsequently to the decomposition of the organic matter and the formation of ammonia, and in the absence of undecomposed organic matter.

4. "That organic matter cannot be destroyed or converted into plant food until it has been dissolved.

5. "That, as nitrification proceeds far more rapidly in a moistened and ærated porous soil than in a liquid, and as the nitrifying powers of soil are capable of cultivation, the process should be carried on by means of filtration, so that the organisms can be cultivated and supplied with food in the filter.

6. "That the most important factor in the processes of decomposition and nitrification, and the subsequent preservation of the nitrates formed, *is an ample supply of air.*

7. "That the suspended matters in sewage should not be allowed to pass on to the land or filter-beds, as they clog the surface, and have to remain until they are decomposed before they can be destroyed."

Time will not permit further quotations from this paper, but it is claimed that the process about to be described fulfils all the conclusions just quoted.

In any method of sewage purification the result must depend to a very large extent upon the skill that has been bestowed upon the design of the works and the care exercised in their construction, quite irrespective of the chemicals used or the process adopted.

PURIFICATION WORKS.

When the sewage arrives at the works it is of the utmost importance that all large substances floating in the sewage, such as corks, rags, brushes, boots, shoes, etc., as well as grease, should be removed by means of scum-boards and strainers, and, at the same time, a certain amount of road sweepings, sand, gravel, and other heavy materials removed by subsidence in a detritus chamber.

In order to effect these purposes in the best and most economical manner, it is advisable to divide the sewer into two channels, as shown by *Fig.* 1, *Plate* I., each channel having a greater width than the sewer.

In ordinary work both channels would be used simultaneously, and the area of the channel being increased, the velocity of the flow of the sewage would be diminished.

The bottom of the channels is sunk to a moderate depth below the invert of the sewer for a certain distance, and then rises up again to the level of the invert.

At each end of the two channels penstocks or sluices are placed to enable one channel to be entirely cut off from the flow of sewage when it is necessary to cleanse it, the sewage then flowing through one channel only.

Across each channel is placed a fixed diagonal or sloping scum-board projecting into the sewage, which arrests all floating matters on the surface; placing the scum-board at an angle of 45° is found to be more efficacious than when the scum-board is placed vertically.

The sewage then passes through two inclined iron screens, the second being finer than the first, which effectually arrest a considerable proportion of the matters in suspension in the sewage.

It is recommended that the first screen be composed of iron bars, placed one-half of an inch apart, and the second screen should have the bars one-quarter of an inch apart in the clear.

The bars should be fixed in an inclined position, no cross-bars, gratings, or perforated plates being used. The object being to enable the bars to be readily cleansed by means of a rake, the teeth of which would be obstructed by cross-bars.

In large works a set of scrapers fixed to endless bands and turned by a handle are now generally used for the purpose of cleansing the screens, and are sometimes driven by machinery, so as to be continually in operation.

The object of placing these screens at an angle of 45° is to enable them to be conveniently raked, and the matter retained by them easily removed.

Having passed the screens, the sewage then receives a dose of chemicals in order to effect deodorization and precipitation.

Various materials are used for this purpose, as mentioned in the former lecture, such as lime, sulphate of iron, black ash waste, alumina, etc.

The author recommends the use of ferozone, which has been used for this purpose in many important sewage purification works both at home and abroad, and has been supplied to the following Government establishments :—Parkhurst Convict Establishment, Dover, St. Albans, Canterbury, Cahir, and at Balmoral Castle, in addition to about twenty towns and institutions, while a still larger number of places have decided to adopt it when the works are completed.

The following analyses show the composition of two sorts of ferozone :—

THE CLIFF, HIGHER BROUGHTON, MANCHESTER,
September 2, 1890.

DEAR SIR,

The following is the analysis of the sample of ferozone which was given to me by Dr. Angell :—

Moisture	20·00
Sulphate of iron, anhydrous	16·28
Sesqui sulphate of iron, anhydrous	6·07
Sulphate of alumina, anhydrous	22·20
Carbon	4·47
Insoluble in water	15·20
Water of constitution and other matter not estimated	15·78
	100·00

This ferozone has been most carefully prepared, and, in my opinion, it is an admirable purifier for sewage. It acts as a precipitant, and also as a deodorizer, and the price of 50 *shillings a ton I consider extremely moderate.*

(Signed) J. CARTER BELL, A.R.S.M., ETC.,
County Analyst for Cheshire, Salford, Birkenhead, etc.

The following is an analysis of red ferozone intended for use with domestic sewage :—

HANTS COUNTY LABORATORY, SOUTHAMPTON,
February 16, 1895.

To the International Company, Limited.

Analysis of Red Ferozone.

Crystalline sulphate of alumina	all soluble 85·1 per cent.	69·0
Ferrous sulphate		10·5
Ferric sulphate		5·6
Ferric oxide	insoluble 14·9 per cent.	12·5
Alumina and silica		2·4
		100·0

This ferozone is very rich in soluble sulphates, and especially so in ferric sulphate.

It forms a powerful precipitant and deodorant.

(Signed) ARTHUR ANGEL, PH.D., F.I.C.

These analyses must not be considered to represent invariably the actual constituents of ferozone. Almost every sewage requires a precipitant specially suited to it; for instance, a purely domestic sewage requires different treatment from a sewage which contains a large quantity of manufacturing refuse, and although the ingredients remain the same, their relative proportions are altered to suit the individual case.

The method of applying ferozone to the sewage is very simple.

Where a supply of water or sewage at a sufficiently high level is available, the best plan is to place the ferozone in one or more dissolving boxes, which consist of a box 15 inches square and 2 feet 6 inches deep, with a perforated false bottom placed 3 inches above the real bottom. Either sewage or water is conveyed by a pipe, provided with a stop-tap, to the space below the false bottom, and rises up through the ferozone. The water in its course up and through the ferozone dissolves the precipitant, and carries it by means of an overflow-lip into the sewage channel. A very small quantity of water is required, and must be proportioned to the quantity of sewage.

A more reliable method of adding the precipitant to the sewage is performed by means of Keirby's patent mixer, which should be used wherever mechanical power is available, whether derived from the flow of sewage or other sources.

This consists of a perforated cylinder containing the precipitant, and placed inside a watertight cylinder with a small space between the two. Near the bottom of the outer cylinder is fixed a pipe connected with the water supply, and furnished with a stop-cock; at another part of the outer cylinder, and at about the same level, is an outlet, to which is coupled a swivel-joint and pipe.

The inner cylinder is fixed upon a spindle, and is slowly rotated either by means of a gas-engine or water-wheel, or other available means. By the rotation of the inner cylinder the water is agitated, and produces rapid absorption. A float is placed in the sewer, and is connected with the outlet pipe; as the flow of sewage increases, the float will raise the outlet, and thus increase the depth of water in the mixer, and submerge a greater quantity of the precipitant, and, consequently, a stronger solution will be discharged, and, *vice versâ*, as the flow of sewage decreases and the outlet pipe falls, the level of the liquid in the cylinder will be lower, and less of the precipitant will be dissolved. Only a very small quantity of water is required to be constantly running through the mixer. The *quantity* does not require varying; it is the *strength* of the solution that is varied, not the volume.

The quantity and quality of ferozone required varies with the nature of the sewage to be dealt with, but usually, for town sewage, about 5 to 8 grains are added to each gallon, which is equivalent to from 6½ to 10cwts. per 1,000,000 gallons, but in small works dealing with a concentrated sewage a larger quantity should be used. The cost of ferozone at the company's works in South Wales and Manchester is 50s. per ton, to which must be added the carriage and hire of sacks.

The cost for chemicals will be, therefore, about 30s. per 1,000,000 gallons of sewage treated, or from ¼d. to ⅓d. per 1,000 gallons.

The sewage, having received the dose of ferozone, passes along the mixing race as shown in *Fig* 1, *Plate* I.

This race should be long enough to allow the ferozone to be well incorporated with the sewage before it enters the tank, and the length will, therefore, depend upon the velocity of the current, but at least 2 minutes should elapse between the time that the ferozone is added to the sewage and the arrival of the treated sewage at the precipitation tank, and, when possible, an interval of 10 minutes is to be preferred.

PRECIPITATING TANKS.

Formerly, these tanks were invariably of rectangular form on plan, with the bottom inclining to a sludge gutter in the centre, which also had a fall towards one end of the tank to facilitate the removal of the sludge deposited therein. These tanks were used either on the continuous flow system, or else on the quiescent plan.

In the former case the sewage flowed continuously through a series of tanks, and this system was generally adopted where very little fall was available. In the quiescent system each tank was filled separately and allowed to stand for an hour or more, then the tank was emptied by means of a floating arm, which draws the sewage from the surface, the floating arm falling as the tanks become empty.

In continuous flow tanks the sewage has generally to be pumped out when it is desired to empty them. Whichever of these two systems is adopted, it is necessary to send men into the tanks to sweep the sludge to the outlet, and when the tank accommodation is very limited, as is too frequently the case, one tank can ill be spared for this purpose. The temptation, therefore, is very great to allow the sludge to accumulate in the tanks for days, weeks, or even months.

The consequences of such neglect are disastrous to any method of chemical purification, for although many deleterious substances may have become deposited in the tanks, and the sewage to a certain extent clarified, the bad gases arising from the decomposing sludge at the bottom of the tank passing into the sewage, and carrying with them myriads of putrefaction bacteria, actually in some cases have rendered the sewage more objectionable from a chemical point of view when it leaves the tank than it was when it entered it, although frequently the appearance of the effluent is good. It was with the view of remedying these defects and affording a means of using continuous flow tanks, from which the sludge could easily and frequently be removed without interfering with the flow of sewage, that the circular continuous upward flow tank has been invented by Mr. F. Pullen Candy.

These circular tanks may be made of any desired diameter or depth (see *Figs.* 2 and 3, *Plate* I.).

A tank 25 feet diameter, with a depth of 16 feet, will treat from 275,000 to 362,000 gallons of sewage per 24 hours.

One 15 feet diameter and 10 feet deep will treat from 59,000 to 79,000 gallons per 24 hours.

One 5 feet diameter and 9 feet deep will treat from 5,500 to 7,500 gallons per 24 hours.

An open channel is formed round the top of the tank, extending for about three-fourths of its circumference. In this channel are inserted three or more vertical pipes which deliver the sewage into the tank a short distance above the bottom, through pipes placed at an angle to the side.

The sewage, rising to the top, flows into a series of parallel troughs laid across the tank, and is conducted by them into an outlet channel extending round the remaining part of the circumference which is not occupied by the inlet channel, and is conveyed by it to the filters to be described hereafter.

We now come to the most important part of the system, viz., the removal of the sludge. Attempts have been made to remove sludge from cylindrical tanks by building them with inverted cone bottoms, furnished with an outlet valve at the apex of the cone.

This plan did not give satisfaction, and involved a very deep and expensive form of tank. The "Candy" tank has a perfectly flat bottom, thus providing a tank of the greatest capacity at the least cost. In the centre of the bottom is pivoted a horizontal perforated pipe which reaches to the side of the tank, this pipe being pivoted on another pipe, which is carried up to within 1 foot 6 inches or 2 feet 6 inches of the full water level of the tank, and at that point the sludge is discharged. The pivoted pipe is capable of being revolved from the outside of the tank by means of suitable gearing, and when the tank is being cleansed the pipe is so revolved. The perforations in the pipe being on the underside thereof, and only a few inches apart, and the pipe itself being but a very little above the bottom of the tank—just enough to clear it, in fact—it will be seen at once that as the rotation of the pipe covers every inch of the bottom, the sludge is drawn or sucked away from the whole of the bottom surface. The pressure of water in the tank forces the sludge through the connecting pipe, and out at a height only 18 or 30 inches below the water level, as before mentioned, from whence it can be run into a pit or pumped to any desired spot. The sludge produced is about twice as thick, and, therefore, of only about half the bulk that the sludge usually is which is drawn or swept from any other form of precipitation tank; and this is a feature of the utmost importance, inasmuch as the sludge is the foulest thing in the whole sewage treatment, and to reduce its bulk or minimize the quantity of water mixed with and polluted by it is a point which cannot be too much valued.

Furthermore, the removal of the sludge as described does not interfere with the flow of the sewage through the tank, and, in fact, when once the "Candy" tank is started its working need never cease; by day and by night the foul sewage, after the addition of the precipitant, is running into the tank and as continuously running out in a comparatively pure condition, the sludge being removed at intervals, thoroughly and perfectly, keeping the tank clean and sweet, and free from all decomposition. Moreover, the rotation of the sludge-pipe can be caused to cleanse the sides of the tank by attaching a suitable arrangement to the pipe. The time taken to remove the sludge is from two to five minutes, varying with the size of the tank.

Very little power is required to rotate the perforated sludge-pipe; a lad can easily do it.

In the case of strong sewage, the tank should be cleaned (by rotating the sludge pipe) once a day, but with a weak sewage every other day would be sufficient, although daily cleansing is always advisable. The old proverb anent the value of cleanliness is very applicable indeed to sewage treatment. It stands to reason that the fouler the thing the greater the need for constant and perfect cleansing, and if a sewage precipitation tank is not or cannot be thoroughly cleansed once in 24 or 48 hours, trouble will ensue.

The method by which the sewage is let into the tank is also of great importance, in order that the effluent water may be clear and bright.

The inventor discovered that if the sewage in the tank has imparted to it a rotary motion, the effluent produced is clearer, brighter, and freer from suspended matter than would otherwise be the case.

The rotary motion is obtained by the flow of the sewage into the tank. The effect of this rotary motion is most remarkable; it has the property of aggregating the fine particles of suspended coagulum, and thereby causing their rapid and complete removal by precipitation when the sewage disperses into the tank, thus obtaining the greatest and most effective work from the least quantity of precipitant, and enabling the precipitation tank to purify the largest quantity of sewage per day.

The "Candy" tank will effectually treat eight times its capacity in 24 hours, and requires only 3 to 6 inches fall for its working, thereby in many cases saving pumping.

By the employment of a flat-bottomed tank and the angular method of sewage inlet, the abnormal depths of vertical tanks that have been proposed can be dispensed with, such depths, indeed, as would convert the tanks into nothing less than large cesspools, and would give no advantage, while having many drawbacks. The total depth of the "Candy" tank need not exceed, according to the area of the tank, from 6 to 15 feet.

For any but the smallest tanks the side inlet is recommended, which is more effective and much more economical than attempting to deliver the sewage from the centre. For small tanks the centre inlet is recommended, as hereafter described.

The general arrangement of a tank is shown by *Fig.* 2, and the section by *Fig.* 3, *Plate* I.

These figures represent a brick tank, 20 feet in diameter and 13 feet deep, constructed at the Nuneaton sewage works. A, A, A are the sewage inlet pipes which convey the sewage from the inlet channel B to points of discharge near the bottom of the tank.

C, C, C are the outlet troughs, placed across the tank and suspended from the girders D, which carry the gearing for working the rotating sludge-pipe E, by means of the spindle F.

The rotating sludge-pipe E works on a joint connecting it to the fixed sludge-pipe G, which discharges into a sludge delivery channel H, and the discharge is controlled by the valve K.

The sludge should be discharged into an open channel to enable the attendant to see its density, as it is not advisable to remove thin, watery sludge.

An iron tank, 4 feet 6 inches diameter and 6 feet 6 inches deep, was supplied to H.M. Government for use at the Cahir Barracks, Ireland.

In this case the centre inlet is adopted.

An iron trough conveys the sewage to the centre of the tank, when it passes to the bottom through a vertical pipe, in which is placed the spindle for rotating the sludge-pipe. A gutter runs round the top of the tank, which receives the overflowing sewage and conveys it away. All the other details are similar to those of the brick tank already described.

There are about twenty of these circular tanks in actual operation at Swinton, Rochdale, Accrington, Nuneaton, Cahir Barracks and other places, and about sixty more are either in course of construction or it has been decided to adopt them.

Where rectangular tanks are already in existence, and it is desired to use them either on the continuous flow or the quiescent system, the principle of removing the sludge adopted in the circular tanks already described can be applied in the following manner:—A wall is built across the tank close to the inlet end, and extending above the level of the water; wide openings are made in this wall close to the bottom of the tank; small openings are to be avoided, as they increase the velocity of the sewage passing through them. An overflow wall is made at the outlet end of the tank, which should extend for the full width. By this means an approach is made to the upward flow of the cylindrical tank; the sewage, passing through the openings in the cross wall, rises in a diagonal direction towards the overflow cill.

If the bottom of the tank falls towards a sludge-gutter, the gutter must be filled up, and the bottom made level transversely; the fall towards the sludge outlet may remain unaltered, although a perfectly level bottom is preferable.

A sludge-gutter is formed on one side of the tank, and the bottom of this gutter is about 18 inches below the water-line in the tank (see *Plate* III.).

Light rolled-iron joists framed together are placed across the tank, and furnished with carriages at each end, which run upon rails placed on the coping of the tank. The girders are caused to traverse the length of the tank by suitable gearing.

From the girders is suspended the travelling perforated sludge-pipe by means of chains, so that the pipe is just clear of the floor of the tank. From this perforated pipe rises a closed pipe furnished with a stop-cock and a charging-pipe. The pipe is turned over the wall of the tank into the sludge-gutter, where it terminates in a water seal.

In order to remove the sludge, it is only necessary to charge the syphon through the cock, open the stop-cock, and the sludge will immediately discharge into the sludge-gutter.

By turning the winch-handles, the perforated pipe travels over the whole length of the tank, and all the sludge lying on the bottom is removed in a few minutes. Twenty-three sets of this form of sludge-removal apparatus have been supplied to places where the works were too far advanced to permit the adoption of circular tanks.

Quiescent tanks are not to be recommended, because it has been found by experience that properly-designed continuous flow tanks are more economical and produce better results; this is accounted for by the fact that in falling into a tank, as is the case in filling an empty tank, the coagulum is broken up into very small pieces, and the inflow into the tank causes a swell, and consequently the sewage is never really at rest, but always in motion. Quiescent tanks also want watching while filling, settling, and emptying, while a continuous flow tank does not require such constant supervision.

The tank being always full, the coagulum does not get broken up in passing into the tank, but can, on the contrary, be made to enlarge or aggregate.

The principal advantage of the quiescent tank has ceased to exist now that the sludge can be removed by the perforated sludge-pipe without emptying the tank.

However, there may occur certain conditions which render it advisable to adopt the quiescent tank system.

In this case it is advisable to form the floor of the tank with a fall from the inlet to the outlet end, with small longitudinal ridges or grooves therein. The sewage is drawn off in the usual manner by means of a floating arm. At the outlet end of the tank a large gutter is formed in the bottom, extending the whole width of the tank. In this gutter is placed a fixed perforated sludge-pipe, which is constructed on precisely the same principles as the travelling sludge-pipe already described. The first inrush of water into the tank washes the sludge into the gutter at the outlet end, where it is removed by the sludge-pipe as soon as the tank is full.

SLUDGE-WELLS.

The sludge from the tanks, no matter of what form, should flow by gravitation into two sludge-wells. The object of providing two sludge wells is to enable the sludge to settle in one while the other is receiving sludge. Each well is provided with means for drawing off the supernatant water into the washing-water chamber, which receives the washing water from the filters and clarifiers; these two waters, which are dirty, must be pumped back to the sewer to receive a fresh dose of ferozone, and be treated again.

The concentrated sludge gravitates from the wells into the rams, whence it is forced by compressed air into one of the sludge-presses, where it is pressed into cakes; this cake drops into a trolley at a sufficiently high level to be run on to low-lying land for filling up purposes, or a cart can be backed directly under the presses and the sludge-cake carried away without a second handling.

CLARIFIERS.

After leaving the precipitation tanks the sewage is conveyed to the clarifiers (*Fig.* 1, *Plate* I.).

These clarifiers are concentrated sand-filters, whereby any flocculent matters that may have escaped precipitation in the tanks are arrested, and thereby prevented from sealing up the pores of the filter-beds; by this means not only can larger volumes of sewage be passed through the filters, but great economy of labour in cleaning them is effected.

By using clarifiers, the area of the filters can be reduced, and a saving is also effected in the quantity of chemicals required for precipitation.

These clarifiers are practically closed filters, and by turning two valves the flow of sewage through them can be reversed, and the retained accumulated suspended matters washed out in three or five minutes and the clarifier is clean again.

The water used in washing the clarifiers must be conveyed to the water chambers at the side of the sludge-pits already described.

The clarifiers are placed in the chamber, as shown on the plan, so that there is a head of 4 feet available for washing them, and this head is so utilized as to save several men's labour daily.

The case or shell of the clarifier is iron, and may be either circular or rectangular, and may have either a watertight cover or may be open, with the sides carried up sufficiently high, about 7 feet, to give the requisite head for cleaning the clarifying material. The clarifiers contain sand and gravel of various sizes, resting upon a perforated false bottom. When in use the sewage is admitted at the top and passes through the clarifying material and out through the false bottom.

When it is desired to cleanse the clarifier the flow is reversed, clarified water from other clarifiers or from a storage tank is sent upwards through the clarifier, and the whole of the material is caused to boil up and become violently agitated and loosened; through the whole mass hundreds of jets of water pass and carry away the accumulated dirt through the wash-out, leaving the clean washed sand behind ready for work again.

By the use of clarifiers a saving is effected in the quantity of ferozone required, because it is practicable to turn a less clear effluent (that is, one produced with less ferozone) into the clarifiers than it would be prudent to send on to the filter-beds.

After leaving the clarifiers, the clarified effluent flows into a channel whence it can be delivered on to any of the polarite filters.

POLARITE FILTERS.

These polarite filters are the most important feature of the nternational Company's process. The filters are formed in the llowing manner (see *Plate* II.):—The depth of filter must depend pon the amount of fall available and the rate at which it is desired filter the sewage per square yard of filter area.

The most economical form of filter has two layers of polarite, nd the sewage may be passed through this filter at double the peed that can be used when there is only one layer of polarite in e filter. The area of filter need, therefore, be only one-half of at with a single layer, and the cost of the filter tank considerably duced.

At the bottom of the filter are placed 3-inch agricultural drain-ipes about 4 feet apart, and surrounded with large stones or oulders. The drain-pipes communicate with square drains formed the side walls, which convey the effluent away. Above the stones layer of gravel of about the size of walnuts and 2 inches thick is aced, then 1 inch of smaller gravel. An inch of fine gravel, hich forms a cushion to carry a 6-inch layer of polarite, mixed ith sufficient sand to make a depth of 9 inches, is laid thereon. bove this, perforated drain-pipes, 4 inches in diameter, are placed, rrounded with coarse gravel, then 1 inch of fine gravel supports nother 6-inch layer of polarite, mixed with sufficient sand to make depth of 9 inches. The filter is finished with a layer of fine sand inches deep at the side and 7 inches at the centre, making a total pth of 3 feet at the side and 3 feet 2 inches at the centre.

The perforated drain-pipes are carried into the side walls of the ters, where they are connected with vertical iron pipes, carried up short distance above the coping, to prevent any dirt or other atter falling down the pipes. These pipes afford the means of oroughly ærating the polarite. It must not be forgotten that e rate of filtration is governed by the speed at which the sewage n pass through the top layer of sand, and this depends upon the ad of water on the filter. This head is usually very small, the nd being only just covered. As the outlet from the filter is nerally open, the sewage passes much more quickly through the rser layers of the filter than it does through the fine sand, nsequently the body of the filter is not saturated with water, as usually the case in submerged filters. Thus the polarite is ntinually receiving a supply of oxygen from the perforated drain-pipes, which form alternately an outlet and an inlet for air, the pipes being provided with suitable cowls for this purpose.

The sewage is admitted to the filter through an open channel kept as high as possible above the level of the sand in the filters. Each filter is provided with two inlets governed by small iron paddles.

A series of steps are formed in the wall of the filter which leads the sewage through the channel into an iron trough resting on the side walls of the filter, from which it overflows on to the sand and passes down through the filter to the drain-pipes laid at the bottom, and then into outlet channels formed at the side of the filter, which communicate with a covered channel formed at one end of the filter and connecting three filters together. From this covered channel at any convenient place an outlet pipe for the filtered effluent is fixed and provided with a sluice-valve.

The action of the filters is as follows:—The sand arrests any matters in suspension which have not been deposited in the precipitation tanks or arrested by means of the clarifiers. The matters in solution are removed from the sewage by being in contact with the polarite.

The action of polarite was fully explained in the previous lecture, but it may be desirable to repeat it now.

Polarite is the trade name of the material successfully used for filtering and further purifying the ferozoned sewage-water from the putrescible matter dissolved therein. It is a black, hard, porous, magnetic and rustless substance, *insoluble* in water and practically everlasting. It is a powerful deodorizer and decolorizer by virtue of the polarized oxygen occluded in its microscopic pores, and constantly supplied by the surrounding air and water. It purifies polluted waters by oxidizing the already partially broken down noxious organic matters dissolved therein, and converting them into innocuous inorganic and saline matters. Its effective action in this direction is probably due to a peculiar power, which Berzelius called "catalytic force." He regarded this power as an indication of electric force different from the ordinary action of electricity. Mitscherlitz calls substances which act like polarite "contact substances," and the mode of action "chemical action or combination by contact." The terms "catalysis" and "contact action" are applied to chemical actions in which the combination of two bodies or the decomposition of a compound is brought about by the intervention of a substance like polarite, which shows no tendency to unite with either of the bodies concerned, and remains unaffected by the changes which take place. In this manner the catalytic power of polarite oxidizes the dangerous organic impurities dissolved in sewage-water, and thereby makes them innocuous.

Foul liquids in their passage through polarite are divided into a cloud-like spray, and thus each particle is subjected to chemical action.

The following is an analysis of polarite made by Sir Henry Roscoe, F.R.S., LL.D., etc., etc., who reported that the "porous nature of the oxide, its complete insolubility, and its freedom from rusting, constitute its claim to be considered a valuable filtering material," and he gives its percentage composition as follows :—

Magnetic oxide of iron	53·85
Alumina	5·68
Magnesia	7·55
Water, with a trace of carbon	5·41
Silica...	25·50
Lime	2·01
	100·00

It contains, therefore, no poisonous metal, is very hard, porous, and absorptive. It extracts iron and lead from water, and destroys organic matter in solution. It is a powerful decolorizer and deodorizer by virtue of the polarized oxygen contained within its microscopic pores. It is extremely durable and magnetic to a remarkable degree, and notwithstanding that iron is the chief element in its constitution, it will not rust.

Polarite filters provided with two layers of polarite purify tank effluents which have been treated with ferozone at the rate of 2,000 gallons per square yard in 24 hours.

Filters with only one layer of polarite will only filter half of the above quantity.

Polarite filter-beds require a few hours' rest occasionally for aeration, and for cleansing the surface sand by a method which will be shortly described. Polarite never requires to be removed or replaced. It is better to lay down several small beds rather than one or two large ones, so that a smaller proportion of the whole filtering area is thrown out of work when the filter is being cleaned. The cost of polarite is £6 per ton at the works in South Wales, to which must be added the cost of carriage.

A cubic yard of polarite weighs about 19cwts., and a ton will, therefore, cover rather more than 6 square yards of filter-bed 6 inches thick.

Where the filtered effluent is taken out of the filter-bed, it is convenient to be able to draw the effluent off at two levels, namely, from the bottom of the filter and also from a higher level. This can be effected by means of a stand-pipe carried up from the outlet pipe from the filter. Off this stand-pipe a branch is taken out at a higher level. If the lower valve is open, of course, the effluent passes out from the bottom of the filter, but if the lower valve is shut the water will rise in the stand-pipe until it overflows into the high level outlet. The object of this arrangement is to make it possible to work the filters occasionally submerged, this being found beneficial for the filters at times. Another valve is placed on each of these branch pipes just beyond the junction of the branch with the stand-pipe, this being used when the filters are being washed by the upward washing process. This process constitutes a very important feature in these filters. Unless it is used frequently the top surface of the sand becomes covered with a thin film of flocculent matter which is nearly impervious to water, consequently a sufficient flow cannot be secured through the filter-bed. To overcome this difficulty the attendant is apt to use a high head of water, thus forcing the objectionable matter further into the sand. The sand in an ordinary filter has, therefore, to be removed and washed either by hand or machinery, fresh sand being substituted for it, all of which involves a great expenditure of time and labour.

The object of the company's patented arrangement is to overcome these two difficulties. This is effected in the following manner:—The flow through the filter is reversed, the filtered effluent from two or more filters passes upward through the filter to be cleansed, and by the provision of suitably arranged troughs, the flocculent and foul matter is rapidly washed off and out of the sand and conveyed to waste, and the filter is aerated and ready for use in a few hours. When it is necessary to wash the upper layer of sand more thoroughly, instead of removing it from the filter, the sand is washed in the filter itself, and thus a large expenditure is avoided.

To keep a filter in proper working order, the upward washing process should be performed daily in the following manner:—It is usual to connect two or three filters together into one group by means of the covered channel already described. When it is desired to wash any one filter, the outlet valve from the group is closed, the paddles on the inlets to the filter to be washed are also closed, while the two or three adjoining filters are kept at work. The sewage consequently passes down through those filters which are at work into the covered channel, and rises up through the drain-pipes at the bottom of the filter to be washed. At the same time men walk along the channels at the side of the filter, and by means of brushes or rakes convey the scum which is loosened by the washing into the side channels. At the same time some sewage is admitted to one side of the filter, and passes over the surface of the sand and over the ridge down the centre of the filter, and washes the scum towards the opposite side channel. At the outlet end of these channels small catch-pits are formed to retain any of the fine sand which is washed into the troughs. This upward washing water is conveyed to a channel, and either taken on to land or conveyed into the chamber adjoining the sludge-pits and mixed with the sewage. Occasionally it is necessary to remove an inch or two of the surface of the sand and wash it. This can be most economically done by using a sand-washing box, which is about 7 feet long, 2 feet wide, and 8¼ inches deep inside. Near one end of the box two divisions are placed across it, having apertures near the top. One end of the box is provided with an overflow lip, and a trough is used to convey sewage from the cascade into the filter into this sand-washing box, which is placed partly on the side trough and partly on the sand. The surface of the top layer of sand is then scraped off and brought to the corner of the filter where the washing box is placed. Sewage is then admitted, and sand is thrown into the trough, conveying the sewage into the box, and stirred up with the sewage. The sand is arrested by the two divisions in the box, and is readily washed, the sewage used for this purpose flowing away through the side troughs in the manner already described. The sand is then lifted out of the box and replaced on the filter bed, and the box removed, the filter then being ready for further operations.

EFFLUENT.

The process is now completed, and the purified sewage issues from the filter in a limpid stream fit to be turned in large quantities into any stream, however small in volume. Unlike the effluents from the now abandoned lime process, the International effluent is not liable to secondary decomposition. Many effluents have been obtained by the lime process which were bright and clear when they left the purification works, and became foul and decomposed a little way down the stream.

The following are analyses of effluents obtained by this process:—

Analysis of Three Liquids from the Huddersfield Corporation Sewage Works at Deighton received from R. S. Dugdale, Esq., the Borough Engineer, March 9th, 1894.

The percentage of purification calculated on the oxygen absorbed (Tidy's method) ... ... = 96·7 per cent.
The albumenoid ammonia (Wanklyn's method) ... = 98·7 ,,

Result of analysis in grains per gallon:—

	Crude Sewage.	Precipitation only.	Polarite Effluent.
Solid matter in suspension	156·45	·7	None.
Dry, 212° F., consisting of organic matter volatile on burning...	75·04	·21	None.
Mineral matter	81·41	·49	None.
Solid matter in solution dried at 212° F., consisting of organic matter and matter volatile on burning...	8·4	14·0	7·2
Mineral matter	43·0	33·6	32·4
Total solid matter	207·85	48·3	39·6
Chlorine in chlorides	8·89	7·0	5·72
Reaction	Neutral	Acid	Acid.
Oxygen absorbed in 15 minutes	8·442	·84	·0665
Oxygen absorbed in 3 hours...	18·48	2·24	·595
Distillation gave ammonia	1·085	·462	·3157
Albumenoid ammonia	1·05	·0805	·0134

(Signed) GEO. JARMAN, F.I.C., *Borough Analyst.*

HENDON EFFLUENT.

Hendon daily collection effluent for month ending January 7th, 1895 :—

	Grains per gallon.
Free ammonia	·0784
Albumenoid ammonia	·1148
Chlorine	5·18
Oxygen absorbed in 4 hours ...	2·18
Physical properties...	Good.

A remarkable growth of protococcus.

(Signed) ARTHUR ANGELL.

The following report on the treatment of the sewage of Acton, Middlesex, by the International process, which has been in operation at that place for over seven years, was made by Professor E. Frankland, PH.D., D.C.L., LL.D., M.D., F.R.S., to Major Tulloch, R.E. (the chief engineering adviser to the Local Government Board), at the request of that gentleman, and Professor Frankland's investigations were conducted entirely without the knowledge of the company :—

"These results show that the raw sewage contained a very large proportion of highly polluting suspended matter, and an unusually large amount of foul organic matter in solution; and further, that the effluents from the subsidence tank and filter were derived from sewage of about equal polluting power, as regards dissolved organic matter.

"In the subsidence tank, the suspended matter was reduced from 240 80 parts per 100,000 of raw sewage to 5·92 parts per 100,000 of tank effluent, whilst the effluent from the filter was free from suspended matter. It was clear and transparent. This is a satisfactory result.

"The effect upon the dissolved organic matter in the subsidence tank is very remarkable, its amount being reduced to little more than one-tenth of that present in the original sewage.

"In its subsequent passage through the filter, the dissolved organic matter is still further reduced to nearly one-sixteenth of that present in the original sewage. It is now in a state of purity greatly exceeding that prescribed by the standards of the Rivers Pollution Commissioners.

"No chemical process of purifying sewage has ever, in my experience, approached this in efficiency; and if the results obtained at Acton can be accomplished in other places, a most important advance will be made in the purification of the sewage of towns.

"I need scarcely add that the effluent from the filter is not only clear, but inodorus and inoffensive. It is, of course, not fit for dietetic purposes; but it may be admitted in large volumes into running water without creating any nuisance."

At an exhibition held last year at Boulogne-sur-Mer, the International process was exhibited, received the Diploma of Honour, and was reported upon by Mr. L. Vauflart, the Chief Chemist of the Departmental Laboratory at Boulogne, who stated

"That the system removes from 84 to 88 per cent. of the organic matter present in the raw sewage."

A bacteriological examination made by Dr. Billet showed that when the original sewage contained 5,250,000 bacteria per cubic centimètre, the liquid decanted after treatment with ferozone contained 812,500 bacteria, and the effluent from the filter 42,000 bacteria per cubic centimètre, or less than 1 per cent. of those originally present.

The highest award of the Sanitary Institute of Great Britain has been made to this process, which also received the Gold Medal of the Paris Universal Exhibition, 1889, and the highest award at the World's Fair, Chicago, 1893.

It seems strange that after years of experience of this process, and the uniformly satisfactory results obtained, the Local Government Board, when application is made to them by a local authority for a loan to carry out sewage purification works on the International principle, should still enforce an old regulation, made before the International process was heard of, compelling the local authorities to purchase a considerable quantity of land upon which the treated effluent can be used for irrigation. It is true that when the International process is employed the Local Government Board will sanction the use of one acre of land for 2,000 population, and where that process is not adopted one acre must be provided for every 1,000 people. It seems absurd to insist upon this useless expenditure of money not only upon the actual purchase of land, which is frequently difficult and costly to obtain, but the use of which involves a greatly increased expenditure upon works, which may involve pumping the sewage in order to put it upon land, when it could pass from the works into the stream without pumping.

Evidence has been given before Committees of both Houses of Parliament, and before Inspectors of the Local Government Board, by engineers and chemists of great eminence, that no object can be attained by putting the effluent from polarite filters on to land. It is to be hoped that this antiquated and unnecessary regulation will soon be revoked.

In the early days of sewage utilization, as it was then called, it was confidently anticipated that large profits would ensue from the application of sewage to the land.

Several companies were formed for this purpose; large sums of money were subscribed, but in not one single instance have the sanguine anticipations of the promoters been realized.

In these days we must be content if we can effect the purification of sewage in the least expensive manner, and not attempt its utilization in a commercial sense.

Nevertheless, one of the questions most frequently asked respecting the International process is, what is the value of the residue?

This must vary not only with the nature of the sewage treated, but also with the demand for manure in the immediate vicinity of the works.

It has not been part of the scope of this lecture to deal with the various methods of treating the sludge.

SLUDGE.

Sludge is the necessary result of any chemical treatment, and a great difference between that produced by the International process and that of most other processes is that International sludge is completely deodorized, while lime sludge, for example, emits a most offensive odour.

The quantity of sludge produced by the International is only one-half of that produced by lime, which is a decided advantage, owing to the reduced bulk of sludge that has to be dealt with.

Sludge can either be run into lagoons and allowed to consolidate, and then removed to the land; it can be run in a wet condition into hollows in the land; or it can be treated by presses and converted into cake, and sold or given away for agricultural purposes. In some places, farmers will pay a small price for it; in others, they will take it away if it is given them, and at Acton, where it is dried and converted into fine powder like guano, it is readily purchased by the market gardeners in the locality.

The following is an analysis of the sludge-cake, showing that International sludge has considerable value:—

THE MANURIAL PROPERTIES OF SEWAGE SLUDGE CAKE PRODUCED AT THE ROYTON SEWAGE DISPOSAL WORKS.

Report by J. CARTER BELL, ESQ., A.R.S.M., F.I.C., ETC., *Analyst for the County of Chester; the County Boroughs of Salford and Birkenhead; also for the Boroughs of Stalybridge, Congleton, Glossop, etc.; Analyst under the Fertilizers and Food Stuffs Act,* 1893, *for the County of Chester and the County Borough of Salford.*

The following are the analyses of two samples of Royton sludge-cake:—

	Sample No. 1.	Sample No. 2.
Moisture	61·000	50·500
Organic matter	14·998	18·630
Nitrogen equals	·694	·732
Ammonia	·842	·888
Silica	11·005	18·226
Lime	3·417	3·673
Oxides of iron and alumina ...	4·433	5·916
Phosphoric acid equals	·487	·520
Phosphate of lime...	1·063	1·135
Chlorides and sulphates of magnesium and the alkalis	3·966	1·803

These two samples are similar in composition to a sample of rotten farm-yard manure, the analysis of which is given below, so that it may be compared with the above:—

Moisture...	75·424
Organic matter	15·922
Ammonia	·736
Phosphate of lime	1·121
Lime	2·142
Oxides of iron and alumina	1·684
Silica	1·611
Chlorides and sulphates of magnesium and the alkalis...	1·360

It may be asked, what is the value of the Royton sludge cake? The reply is:—

That in my opinion it has the same value, weight for weight, as rotten farm-yard manure.

(Signed) J. CARTER BELL.

MANCHESTER,
25th April, 1894.

WATER PURIFICATION.

Although, as stated at the opening of this lecture, it is not intended to discuss the whole question of water purification, it may be well to mention that for water purification ferozone and precipitating tanks are not required, and only the polarite filters as described for use at sewage works are employed.

A modification of this system of using polarite has been adopted at some waterworks, for instance, Reading and Keighley, where polarite chambers are employed.

At Keighley the water is first passed through ordinary sand filters and then through chambers filled with polarite alone, in pieces about the size of walnuts, and not in the finely-granulated form which is used when the polarite is mixed with an equal quantity of sand.

One condition of its successful use is that the water before reaching it must be in a clarified state, *i.e.*, as free as possible from all suspended matter, for polarite has no more effect upon solid impurities than sand, and if the water is allowed to pass through it without being first deprived of the suspended impurities the medium would become clogged and its free oxidizing action interfered with.

At Reading the turbid water of the river Kennet is first passed through a chamber filled with coke, and then down through a chamber filled with polarite to a depth of 2 feet 6 inches, then down another similar chamber, the water thus passing through 5 feet of polarite. The loss of head in these chambers is very small.

Each chamber has an area of 40 square yards, and from January 1st, 1894, to August 31st, 1894, upwards of 541,000,000 gallons have been effectually purified by means of polarite in these polarite chambers, being filtered at the rate of 13,917 gallons per square yard per 24 hours.

This is far in excess of the speed of filtration recommended; but at Reading the results obtained have been satisfactory, and the manager of the Corporation waterworks reports:—"Since the introduction of polarite we have had no complaints as to the quality of the Reading water; previously they were of every-day occurrence."

Another advantage of this rapid rate of filtration is that the polarite chambers do not become frozen as the sand filter-beds are liable to do.

During the recent severe frost the whole of the water supply of Reading was passed through the polarite chambers with good results, the sand filters not being available owing to the frost.

The borough engineer of Keighley writes, under date 22nd January, 1895, stating that he considers polarite does a great deal towards purifying and brightening the water, and sends the following copy of recent analyses. No. 1 is the water before being purified, No. 2 the same water after passing through polarite:—

Copy Analysis.	No. 1.	No. 2.
Appearance in a 2-foot tube.. ...	Slightly turbid, yellowish brown	Colourless.
Smell when heated to 100° F. ...	None	None.
Chlorine in chlorides	·75	·7
Phosphoric acid in phosphates ...	—	—
Nitrogen as nitrates	None	None.
Ammonia, free...	·0084	·0075
,, albumenoid	·0122	·0046
Hardness	1·3°	1·3°
,, after boiling	1·3°	1·3°
Lead	None	None.
Reaction	Acid	Neutral.
Total solid matter dried at 212° F....	4·4	5·4
Sediment on standing some time ...	Small amount	Small amount.
Microscopical examination of sediment	Fragments of vegetable fibre, oxide of iron, no life	Vegetable *débris*, oxide of iron, no life.
Oxygen absorbed in three hours ...	·087	·0481

No. 1 water taken from gathering ground. No. 2 water supplied from clean water tank. Results given in grains per gallon.

Not only has polarite the effect of removing the dissolved impurities from water, but it also removes colour to a remarkable degree, and as most of the large towns in the north derive their water supply from moorland water, which is frequently impregnated by peat and consequently much discoloured, this is an important matter.

In removing the colour from water by means of polarite, the peaty acid is also removed which has such an injurious action upon lead, and contributes so largely to lead poisoning in many towns supplied with soft, peaty water.

Quite recently the Home Office has requested the company to tender for the supply of one clarifier and sufficient polarite for two filters, each 18 feet square, filled to a depth of 3 feet. This order was in consequence of an experiment made in the presence of Lieut.-Colonel Beamish, R.E., showing the effect of passing a sample of Dartmoor water, which is strongly impregnated with peat, through polarite, with the result that the purification effected was 62 per cent., as shown on the following table.

The following analytical table illustrates the remarkable effect of polarite upon different kinds of waters, both as to their physical properties and as to their dissolved organic impurities :—

Description of Sample.	Date of Analysis.	Name of Analyst.	Physical Properties.		Albumenoid Ammonia Grains per Gallon.		Percentage of Purification.
			Crude.	Filtered through Polarite.	Crude.	Filtered through Polarite.	
Milford Haven, River Water	1891	Angell	Yellow, turbid	Bright, colourless	·026	·008	70
Adelaide, Australia, River Water ..	,,	,,	Deep yellow, very dirty and turbid	Colourless, bright	·0333	·00378	89
Kingston, Northampton, River Water...	,,	,,	Yellow, turbid	Bright, colourless	·015	·00112	93
Ostend, River Water	1893	,,	Yellow, dirty	Colourless, bright	·03444	·00924	74
* Mansion House Chambers, Deep Artesian Well	,,	,,	Yellow, slightly tinted	Colourless, bright	·00392	·00308	22*
Chester, River Dee	,,	,,	Yellow, pondy odour	Colourless, odourless	·0301	·00273	92
Belfast, Public Supply	,,	,,	Yellow, bad odour	Bright, colourless, no odour	·015204	·00795	48
Dartmoor, H.M. Prison, Peaty Moor Water	,,	,,	Dark sherry, brown	Colourless, bright	·0158	·00616	62

* This water in its crude condition is practically pure, hence the small percentage of purification.

The following table of analyses shows the analytical results of various waters before and after filtration.

It will be seen by this that polarite reduces the albumenoid ammonia (the polluting matter in solution) to an enormous extent, and at the same time gives the water the freshness of a pure spring supply. For comparison, the albumenoid ammonia of the Liverpool water supply is shown in sample W, and from this it is apparent that the Chester water, V, from the river Dee, has been purified by polarite to a high degree, illustrating the remarkable fact that sand-filtered water can be further purified by polarite to the extent of 72 per cent. It will be observed that the impurities in the Liverpool sand-filtered water are nearly three times greater than that of the polarited water of the river Dee.

Analytical Table Illustrating the Increased Purification produced by the Filtration of Water through Polarite, as compared with ordinary Sand Filtration.

	Source.	Filtering Medium.	Free Ammonia.	Albumenoid Ammonia.	Analyst.
			In parts per 100,000.		
The smaller the amount of albumenoid ammonia, the greater the purity.					
A	Severn	Sand	·00660	·0115	Professor Corfield.
B	,,	Polarite	·00125	·0060	,,
C	Annan	Sand	—	·0161	Dr. Maxwell Ross.
D	,,	Polarite	—	·0056	,,
E	Worth Park	Sand	·0450	·0166	Professor Corfield.
F	,,	Polarite	·00840	·0074	,,
G	Colne	Sand	·01100	·0140	A. W. Stokes, F.I.C., etc
H	,,	Polarite	·00100	·0030	,,
I	Hastings	Sand	·0137	·0148	Dr. Otto Hehner, F.I.C.
J	,,	Polarite	·0047	·0082	,,
K	Reading	Unfiltered (average)	·0309	·0173	Dr. Ashby.
L	,,	Polarite	·0060	·0050	Professor Attfield.
M	Leicester	Unfiltered	·0040	·0204	Leicester Corporation.
N	,,	Polarite	0010	·0060	,,
O	Nile Water	Unfiltered	·0033	·0214	H. D. Richmond, F.C.S.
P	,,	Polarite	·0023	·0048	,,
Q	Severn	Sand	·0076	·0244	Dr. Arthur Angell, F.I.C.
R	,,	Polarite	None	·0042	,,
S	Mostyn	Unfiltered	·0130	·0170	W. F. Lowe, F.I.C.
T	,,	Polarite	·0010	·0040	,,
U	Chester	Sand	·0030	·0110	,,
V	,,	Polarite	·0010	·0030	,,
W	Liverpool	Sand	·0017	·0084	R. H. Harland, F.I.C.

In places where open filter-beds cannot be adopted, the asphaleian filter, supplied by the International Company, may be used with advantage. This filter is worked under pressure, and will purify 130 gallons of water a square foot per hour. The asphaleian apparatus is a closed cylinder, of cast or wrought iron, or, for lightness, of steel, in which polarite is placed. It is especially useful in cold countries, where open filter-beds are unsuitable owing to severe frosts, and in hot countries where vegetation luxuriates, and soon coats the surfaces of open filter-beds with vegetable growths, which stop their action. The closed cylinders are provided with rotating arms, to stir up the surface sand for cleansing it. On reversing the current of water and opening a scum-cock at the top, the dirt which had collected on the surface is rapidly washed away, and the filter again ready for use.

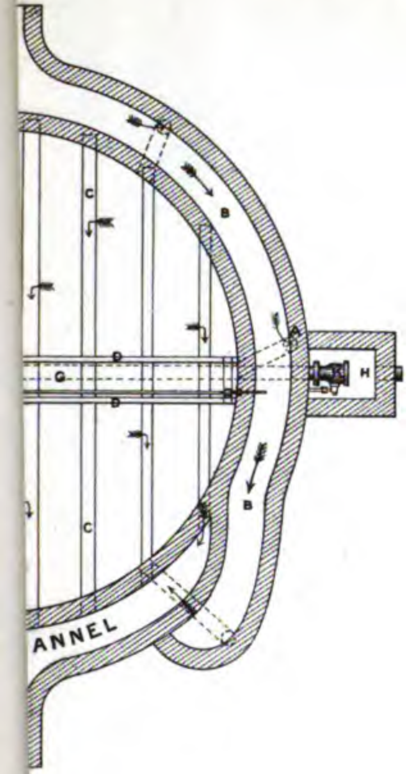
The filters referred to in the table, page 94, as "Mansion House Chambers," are of this high-pressure type, and have been in constant and successful operation for over six years, and similar filters have been supplied to the Government of Mysore. These asphaleian filters are specially adapted for use in barracks and hospitals, because it has been found that in these places germ-laden air contaminates the water in cisterns and filters.

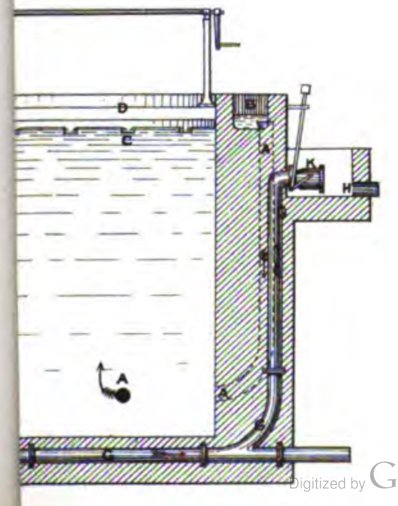
In passing through a sufficiently thick layer of polarite, these germs are removed and the air becomes sterilized. In these filters no air is admitted without first having passed through a sterilizing chamber containing polarite, and the water is kept pure and uncontaminated.

In conclusion, the author must express his acknowledgments for the valuable assistance that he has received from the officials of the International Water and Sewage Purification Company, and to express his opinion that if as great improvements are made in the treatment of sewage during the next seven years as have been made in the last, the great problem of sewage disposal may be considered to be definitely settled.

PURIFICATION PLATE I.

2.





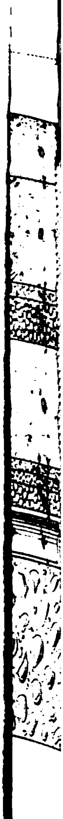
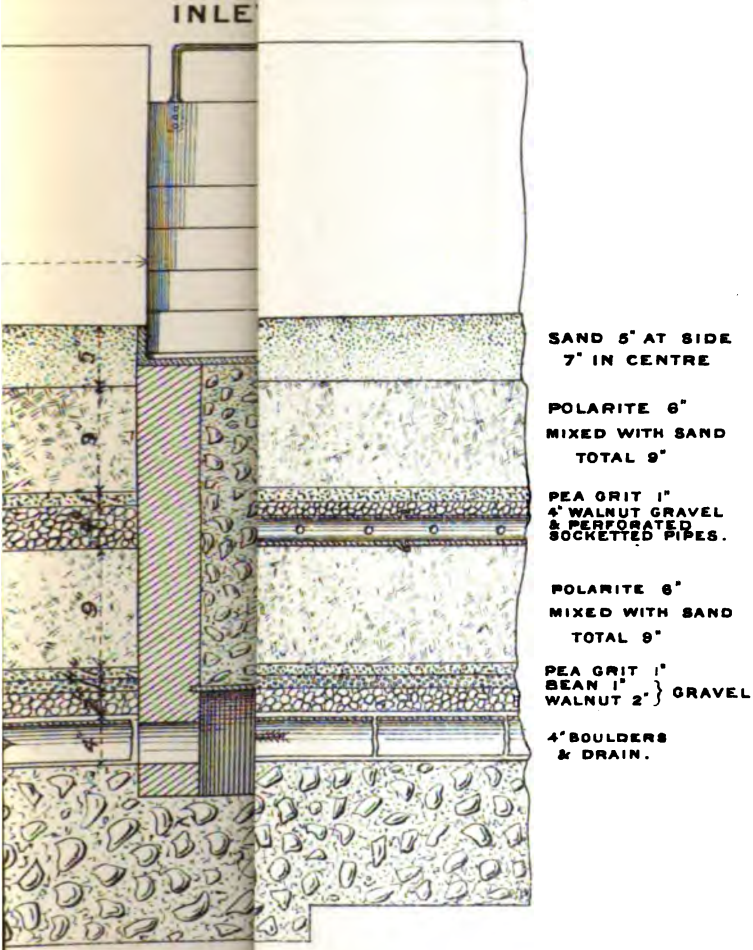


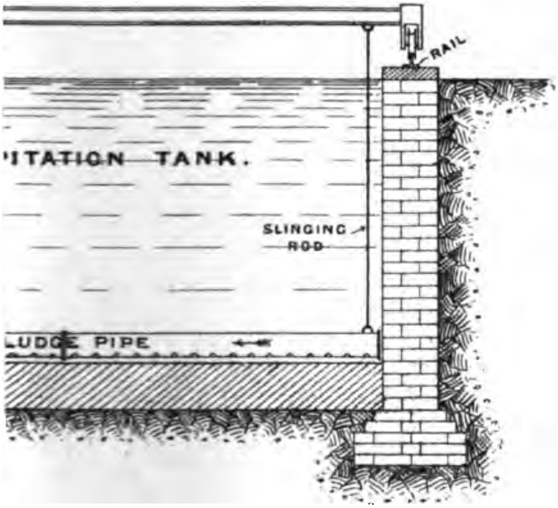
PLATE II.


INLE
5
9
9
SAND 5" AT SIDE
7" IN CENTRE
POLARITE 6"
MIXED WITH SAND
TOTAL 9"
PEA GRIT 1"
4" WALNUT GRAVEL
& PERFORATED
SOCKETTED PIPES.
POLARITE 6"
MIXED WITH SAND
TOTAL 9"
PEA GRIT 1"
BEAN 1"
WALNUT 2"
GRAVEL
4" BOULDERS
& DRAIN.

ION.

PLATE III.

'S PATENT
ULAR TANK



PAPER VI.

FORTIFICATION IN SAVAGE WARFARE.

By Major W. D. Conner, R.E.

(*Lecture Delivered at the S.M.E., 20th and 21st February,* 1895).

It needs, I think, but a brief residence at the S.M.E., Chatham, to convince anyone how multifarious are the acquirements of an Engineer officer now-a-days, while a glance at the *R.E. Journal* will disclose an astonishing diversity in our occupations during peace time. Nevertheless, we must always remember that the cause and object of our existence is war, and that the one science in which we all must be specialists, is what we call in our military schools "fortification," but what is more exactly described as "military engineering." Lest, however, I be deemed presumptuous in coming to the headquarters of my Corps to address you on such a subject, let me hasten to inform you that I have no new theory or principle to air. I merely propose to lead some of the junior officers along paths which may be unfamiliar to them, and to examine, from an Engineer's point of view, some incidents in campaigns of minor celebrity which have taken place in modern times.

With the exception of the Mutiny, the Boer War in 1881, and the expedition against Arabi Pasha in 1882, all the campaigns in which we have found ourselves engaged since the Crimea have been against uncivilized enemies, and though the likelihood of a gigantic

European war is great, the probability of a recurrence of petty wars on our various frontiers is still greater, so it cannot be deemed waste of time to consider in what points fortification in savage warfare differs from that taught in our text-books, in which the enemy is assumed to be possessed of the best devices that can be invented for compassing our destruction.

Our uncivilized enemy possesses, as a rule, superiority in numbers, individual agility, and marching powers, and is able to conduct operations unhampered by thoughts of supply, care of wounded, baggage, and such like impedimenta. To counterbalance these advantages, he is generally wanting in organization and discipline, his arms indifferent and ill-cared for, and his shooting inaccurate, while his supplies of ammunition are frequently limited. He probably possesses no artillery, or, if he does, is unable to use it properly, and though disdainful of death, and gifted with courage of the highest order, he is generally lacking in coolness, and impatient of reverse. In many cases his force is wanting in cohesion, and there is amongst the chiefs jealousy and distrust, which are apt to show themselves when things go wrong, even if they have remained hidden till then. In a European war, the Red Cross is respected by all combatants, whereas, in dealing with a barbarous foe, the commander of a force must take the most careful precautions for the safety of his sick, wounded, and non-combatants, the protection of whom will greatly incommode his arrangements.

Moral, which is important in all warfare, is everything when dealing with savages, so it is a sound maxim *always to take the offensive* when possible, and many of our worst defeats have been brought about by the neglect of this principle. Obviously, however, it is not always desirable to come to close quarters; against overwhelming odds, or in engaging an enemy armed only with weapons for cut and thrust, it is manifestly preferable to keep them at a distance, and in many cases the disparity of forces restricts one's choice between taking the defensive or being annihilated. Here, readiness of resource, and the faculty of utilizing the worst materials, will be more than ever valuable, and more frequent opportunities will be afforded to junior officers than on occasions when larger bodies of troops are manœuvred.

The works to be constructed will doubtless be modest from an engineering point of view, but they must not on that account be viewed with disdain. They are a service for which every Engineer officer should be prepared, and though many of the ideas appear to be simply the dictates of common sense, yet it is from omission to utilize these ideas that disasters have occurred.

One form of aggression, peculiar to some savages, is the individual night attack, a method which by no means finds favour in the eyes of European troops, seeing that the success of the enterprise results only in the temporary confusion of the defence, whilst its failure involves the destruction of the assailants. Over the savage nature, however, individual secret action exercises a potent charm, as involving courage and stealth with the precious possibilities of bloodshed and loot. Be that as it may be, the notion of stealthy marauders crawling about at night, though seductive to the principal actors, is eminently distasteful to the British soldier, who likes his fighting conducted according to his own ideas of fair play, and, if possible, by daylight.

But different people have different ideas—as in the early wars in Burmah, where the Burmese frequently remonstrated with us because, contrary to all precedent, we used to continue hostilities during the heat of the day, and occasionally capture whole parties asleep—and one should not despise an enemy because he shows subtlety in attack, and even in open fighting it must be clearly understood that the savage does not always meet his civilized enemy with any feeling of inferiority—far from it.

Where the attacking force possesses no artillery, the defence will have no need of thick parapets, overhead or splinter-proof cover, while accurate long-range rifle fire need not be feared, for even if the savage could shoot effectively at long ranges—which he cannot do—he would hesitate to run the risk of wasting shots, considering the difficulty of replenishing his store—"ammunition columns, reserves, regimental arrangements," and the like, being to him so many idle words.

Under these circumstances, the construction of a defensive work will be of extreme simplicity, the chief essentials being a clear space around it, to prevent surprise and to allow of effective fire, and an efficient obstacle. The latter may be called upon to afford protection against—(1), a close fire; (2), an attack *en masse;* or (3) individual marauders whose operations will be conducted under cover of darkness.

(1) needs no comment, though it may be pointed out that no allowance used to be made for the drop of the enemy's bullets, out of sight being out of shot under the circumstances.

(2). The assault may be delivered with great determination and suddenness, and it is of the utmost importance that not for an instant should the slightest approach to weakness or wavering show itself on the part of the defence. It is not sufficient, as may be the case in European war, that the obstacle should break the formation of the enemy's attack. Whether parapet, palisade, wall, or bush, it must be sufficiently strong to ward off hand-to-hand fighting, and to keep back the assailants till they are all killed or dispersed.

(3). Where individual night attack is apprehended, flank defence is advisable, as there must be no sheltered spot close at hand where a spy can lie hidden till he can find a suitable opportunity for shooting a sentry or crawling into the work. Of course, no complicated trace is admissible, a small projection at the angles, or, in the case of a wall, a rough machicolation of stones at the top, being sufficient. Mere technical skill must be secondary to a ready ability to grasp the situation and to quickly utilize available materials. The obstacle is all-important, and until it is in a fairly completed state, to waste time over elaboration of detail is to court disaster.

New Zealand.

From the year 1860 to 1865 we had to contend with three distinct parties among the natives. With one of these we had no quarrel whatever; they joined the others from the mere pleasure of fighting. The Maoris possessed the highest military qualities, coolness, wariness, spirit, determination, judgment in taking up positions, and sagacity in knowing when to vacate them. They were never depressed by reverses, and the following incident will demonstrate their courage.

In the attack on the Orakau Pah in 1864, one of the Maoris, a man of gigantic stature, had his left leg broken and his right shin bone splintered. Though undoubtedly suffering terrible agony, he had his limbs bound up in rude splints and continued to fight bravely till shot through the head.

They were very successful in ambuscade, and their skill in escaping through marshes and jungle apparently impassable, was remarkable. Once, a pah, which had contained a numerous garrison on the preceding evening, was attacked on two sides by an imposing force in the early morning, but no more formidable tenants were found than a blind man and an old woman.

In the attack on the redoubt of Rangariri in 1863, after two assaults had been repulsed with loss, it was resolved to try mining, and a gallery was actually driven under the parapet, but, as all the fuze had been mislaid, underground operations were abandoned.

Great hardships were sometimes endured by our men. On one march they were obliged to subsist for two days on horseflesh.

That these natives were particularly good at the construction of rifle pits and entrenchments will be gathered from an account of "The Attack on the 'Gate Pah.'"

On the 27th April, 1864, a British force 1,695 strong, under General Cameron, found a body of insurgent Maoris near Tauranga occupying a strong position consisting of a shelter trench thrown across a neck of land between two marshes (*Plate* I.). The highest point of the position was in the centre, and from it the ground fell about 50 feet to front and rear, the summit being occupied by two oblong redoubts, or rather immense traverses, containing several blindages with arrangements for firing from inside, as well as innumerable open passages, securely defiladed from flanking fire by overlapping traverses, while all round the redoubt was a palisade standing in the open. The blindages were roofed with wattles thatched with fern and covered with earth. On arriving in front of this position, though its garrison was estimated at from 150 to 300 men, it was deemed too strong for immediate assault, and preparations were made for an artillery attack next morning, while under cover of night the 68th Regiment, 650 strong, succeeded in making a very difficult march through the marsh on the right flank of the defence, and took up their position about half a mile in rear of the pah, without being perceived by the garrison, whose attention was diverted by a false demonstration on the other flank. At 6.30 a.m. on the 28th fire was opened from a miniature siege train consisting of one 110-pr., one 40-pr. Armstrong, two 24-pr. howitzers, two 6-pr. Armstrongs, and some mortars. The ranges were very short, the guns being divided into four batteries and protected by light epaulments. For some hours they did not seem to make much impression, but this may have been due to the fact that the fire was directed on a flagstaff which was supposed to be in the work, but which eventually proved to be 100 yards behind it. To this terrific bombardment no reply whatever was vouchsafed, the Maoris lying quietly in their blindages and trenches under a hurricane of shot and shell. By 4 p.m., however, one angle of the big redoubt was completely breached, and the assault was ordered. The storming party consisted of 150 men of the 43rd L.I., and the same number from the Naval Brigade—bluejackets and marines. One hundred and seventy men of the 70th Regiment were extended to keep down the enemy's fire, and follow as a support to the assaulting party, while the reserve consisted of 300 men. The storming party, formed in a column of fours, with two sailors and two soldiers abreast in each section, effected an entry with little loss, but scarcely were they in the work when they were attacked with great vigour by the garrison, and after a short struggle turned round and rushed pell mell out of the breach. This sudden panic may probably be explained by the troops knowing nothing of the blindages and trenches of the defence, and being unexpectedly assailed when they reached the summit of the earthwork by the fire of a hidden enemy. The supports were unable to check the rout, and as the Maoris concentrated their fire on the mass of the fugitives, great loss was experienced. It was considered unadvisable to renew the assault before next day, and a line of entrenchments was then thrown up across the front of the work, about 100 yards from it. When the assault was made, some of the garrison had attempted to escape, but were driven back into the pah by the 68th. However, when morning dawned, it was found that the pah was deserted, the enemy having escaped during the night, which was very dark, and by crawling through the swamps eluded the vigilance of the 68th, as the latter had got past them on the previous night. Our loss was 10 officers and 27 men killed, and 4 officers and 72 men wounded, while that of the Maoris in killed and wounded was computed at 30. That the failure of this attack was not due to the inferior quality of the troops concerned in it is proved by the fact that, four weeks later, the 43rd L.I., of whom the colonel and six officers were killed, and two more wounded, at the Gate Pah, distinguished itself greatly at an assault on the Le Raunga Pah, which, occupying an almost exactly similar position to the Gate Pah, they took at the point of the bayonet, killing over 110 of its garrison. A French writer (Pierron) describes the works of the Maoris as the perfection of shelter trenches, cover from direct fire being secured by the depth of the trenches, and from curved by the construction of blindages. The plan of the work, with its maze of passages and traverses, well calculated to confuse the assault, is worth examination; also the drawing of the palisade, which is difficult to break up with artillery fire, permits of the defenders firing under it along the surface of the ground, and is sufficient to break the formation of an attacking party. It may not be hypercritical to point out that more breaches might have been made, assaults might have been delivered by several separate columns, the fronts of which might have been wider than a section of fours, and that soldiers and sailors are not always seen to the best advantage when intermingled.

THE ABYSSINIAN EXPEDITION OF 1867-68

next claims our attention, but as there was only one small action fought, I will hastily pass it over, merely pointing out that it was an example of most excellent arrangement throughout, and of the merits of an Engineer officer in supreme command.

The 10th Company, R.E., three companies of Madras and two of Bombay Sappers, with a large number of R.E. officers, mostly from India, did splendid service, constructing piers and stores, sinking wells, making roads, and a narrow-gauge railway, 12 miles long, from the landing place, Zoola, in Annersley Bay, to the foot of the mountains. This railway was entirely made, under the direction of R.E. officers, by working parties of native infantry, with a few civilian plate-layers, and took over three months to complete; but great difficulties had to be contended with. No less than five descriptions of rails were provided, with four different principles of fixing, and as the disembarkation of the plant just kept pace with the requirements of the work, the line was fed from hand-to-mouth, and there was no time for stacking or sorting.

The tender of an eminent contractor for making the line was £72,000, and its cost, by military labour, exclusive of rails and plant, only came to £6,000, so a great saving was effected.

At the assault on Magdala on the 13th April, though barrels of powder were available, it was found that the powder bags had been left behind. This was, at the time, much commented on by the newspaper correspondents, but it was afterwards shown that the bags had been abandoned in the hurried march by order of a general officer, and had been then stolen by some natives. Moreover, if they had been used, they could not have failed to blow the assaulting party over the precipice, so their non-appearance may be deemed to have been providential.

ASHANTI, 1873–74.

Few countries are naturally more unfavourable for the practice of the principles of field fortification than that through which our troops marched from Cape Coast Castle to Coomassie, seeing that it is thickly covered with forests of very large trees, all of hard wood, knitted together by dense undergrowth and creepers. The track crossed one large river (the Prah) and several smaller streams, while the deadly climate almost precluded the idea of Europeans working; native labour was difficult to procure, and when obtained proved to be of the very worst quality. There was but little time to execute anything, as the extent of the campaign was limited to the duration of the so-called dry season, December to March.

As a type of numerous small works built may be mentioned one called Fort Cambridge at Mansu, a clearing half-way between the coast and the Prah. It was surrounded by a shelter trench, lined with fraises, and a stockade of bamboos, laced together with split bamboos and creepers. A large ant-hill in the centre was dug out and formed into a sort of keep, where 20 men could defend themselves, and interior trenches were dug, in which the native labourers could conceal themselves.

The difficulty in clearing the ground with untrained labour was very great, every tree being so entwined with creepers that when cut it would sometimes refuse to fall, and would remain standing in its place supported by others, till occasionally four or five trees would have to be brought down together. The masses of branches and foliage knotted together were enormous, and as the trees fell, huge ants' nests would be broken, and the ants, running all over the place, used actually to drive the men from their work. So wet and full of sap were the trees, that it was utterly impossible to burn them.

On arrival at the Prah, over which a bridge for infantry was to be thrown, it was found to be from 50 to 70 yards wide, from 8 feet to 10 feet deep, with precipitous banks, a fairly regular bottom, and a strong current, subject to very rapid rises and falls. There was no means of driving piles, and such light trestles as the tackle on the spot could get out would undoubtedly have been carried away in a short time, so under the circumstances cribwork piers were decided upon (*Plate* II.). These were made of timbers lashed together with rope, tightened by wedges, and were rectangular in plan, 8 feet by 6 feet at bottom, battered in to 4 feet by 3 feet at the level of the surface of the water, the portion that was to be above water being added afterwards, so as to facilitate the sinking of the lower parts in position. Each of the latter was floated out to its proper place in a vertical position, barrels being attached to it by slip-knots to give additional buoyancy, as the wood was heavy, while to make the whole remain upright a sandbag was lashed to each corner of the bottom, which was a cross-barred frame. As soon as this was floated into its proper place in the line of the bridge, a raft, loaded with filled sandbags, bread bags, and rice boxes, was brought alongside of it, the slip-knots let go, allowing the barrels to float up, and the sandbags, etc., then thrown into the crib to sink it in its proper position. The parts of the cribs above the water would then be super-imposed, and rough transoms put on them. When in position, all the cribs were lashed together with a 3-inch rope, and each one strutted up on the down-stream side, while an apron of sandbags and rice boxes was thrown in to prevent movement. The bridge was completed by placing on the piers some light built-up girders, which had been sent out from Chatham, the roadway secured with telegraph wire and iron spikes, and a handrail was subsequently added. This bridge, which allowed of a clear roadway of 5 feet width, was built in 61 hours, and was found by the expeditionary force, on their return from Coomassie six weeks afterwards, to be as good as new, though a very severe flood, which rose nearly to the roadway, had burst upon it in the meantime.

ZULU WAR, 1879.

A complete contrast to the thick jungles of the Gold Coast is found in the open grass plains on which the campaign against the Zulus was fought. An account of the attack on Rorke's Drift will serve as an excellent illustration of the merits of hasty defences (*Plate* III.)

Shortly after 3 o'clock on the afternoon of the 22nd January, 1879, a fugitive brought to the detachment at Rorke's Drift the news of the annihilation only an hour before of the British force at Isandhlwana, seven miles away, by a Zulu army of nearly 14,000 men. There was but little time for preparation, but that little time was utilized to the utmost by Lieutenants Chard, R.E. (now major and V.C.), and Bromhead, 24th Regiment (afterwards V.C.). The meagre garrison numbered but 104 fighting men, mostly of the 24th Regiment, besides 35 sick men in the hospital. There were also some native troops, but they bolted as soon as firing was heard in the distance. Tents were struck, the storehouse and hospital—which were built of stone, but with thatched roofs—barricaded and loopholed, the two buildings, which were 30 yards apart, being connected by a parapet made of a few wagons and a number of bags of Indian corn. As the length of the parapet was too great for the garrison, an inner retrenchment of biscuit boxes was made across the enclosure; but this was only two boxes high when the attack commenced. The following is an extract from Lieutenant Chard's description of the struggle:—

"About 4.30 p.m. 500 or 600 of the enemy came in sight round the hill to our south, and advanced at a run against the south wall. They were met by a well-sustained fire, but notwithstanding their heavy loss continued to advance to within 50 yards of the wall, where they met with such a heavy fire from the wall, and cross-fire from the store, that they were checked, but taking advantage of the cover afforded by the cookhouse ovens, etc., kept up a heavy fire. The greater number, however, moved to the left without stopping, and passing the hospital, made a rush at our north-west wall of mealie bags, but after a short but desperate struggle were driven back with heavy loss into the bush around the work.

"The main body of the enemy were close behind, and had lined the ledge of rock and caves overlooking us about 400 yards to our south, from where they kept up a constant fire, and advancing somewhat more to their left than the first attack, occupied the garden, hollow road, and bush in great force. Taking advantage of the bush, which we had not had time to cut down, the enemy were able to advance under cover close to our wall, and in this part soon held one side of the wall, while we held the other. A series of desperate assaults were made, extending from the hospital along the wall as far as the bush reached, but each was most splendidly met and repulsed by our men with the bayonet. The fire from the rocks behind us, though badly directed, took us completely in reverse, and was so heavy that we suffered very severely, and about 6 p.m. were forced to retire behind the retrenchment of biscuit boxes. All this time the enemy had been attempting to force the hospital, and shortly after set fire to its roof. The garrison of the hospital defended it room by room, bringing out all the sick who could be moved before they retired. From the want of interior communication, and the burning of the house, it was impossible to save all. With most heartfelt sorrow I regret we could not save these poor fellows from a terrible fate. Seeing the hospital burning, and the desperate attempts of the enemy to fire the roof of the stores, we converted two mealie bag heaps into a sort of redoubt, which gave a second line of defence all round. As darkness came on we were completely surrounded, and, after several attempts had been gallantly repulsed, were forced eventually to retire to the middle, and then inner wall of the kraal to our east. The position we then held we retained throughout. A desultory fire was kept up all night, and several assaults were attempted and repulsed, the vigour of the attack continuing till after midnight. The men, firing with the greatest coolness, did not waste a shot; the light afforded by the burning hospital being of great help to us. About 4 a.m. next morning the firing ceased, and at daybreak the enemy were out of sight over the hills to the south-west."

About 400 dead Zulus were found on the ground round the post. It will be seen that the position was by no means naturally a strong one, the proximity of the bush, garden, and outlying buildings being a weak point, while the defenders on the northern side were exposed to a reverse fire. The value of a retrenchment is here clearly demonstrated.

THE AFGHAN WAR, 1878–80.

Though all the Afridi tribes round the Khyber Pass were supposed to be "friendly," yet, on the commencement of the campaign, they used to attack our outposts almost nightly as soon as darkness afforded a decent cloak for their misbehaviour. As these outposts, or picquets, were very necessary to give security to the large encampments, it speedily became imperative to put them in a state of defence sufficient to withstand straggling and individual attacks. The loose stone which covered the ground afforded an excellent material for parapet and obstacle combined (*Plate* VI., *Fig.* 1). The enclosure within the wall was often circular, and, of course, varied in size, strength, and elaboration according to its position and the purpose for which it was required, as well as to the size of its garrison. The wall itself was made too high to be rushed and too strong to be pulled down. Behind it was a banquette, with steps down into the interior. The post being invariably on high ground, a knoll with steep sides was, if possible, selected, so that the height of the obstacle could be increased by scarping the ground on the outside. Precautions had to be taken to prevent the head of the sentry, when standing on the banquette, from being seen against the sky-line from outside the enclosure. This was done by placing rough stones or sandbags on the wall, allowing spaces for firing through, while a complete view of the ground just outside was obtained by a slight irregularity of trace, or by large stones laid on the top and projecting over the front, with sandbags laid on them, so as to allow of the exterior of the wall being seen. The entrance was often closed by loose planks lying horizontally on edge, one over the other, the ends fitting in between stout uprights. This is an excellent form of entrance to a work built for purely defensive purposes, as, each plank being separate, it can only be opened gradually, and it would be very difficult to destroy except by attacking the planks seriatim. This stone-wall type of fortification has long been in vogue amongst the Afghans themselves, and the works, which they call "sungars," have occasionally proved useful to them against our troops, as in the action of Futtehabad.

In every Afghan village there can be found, where we have not blown them down, one or more towers, used as strongholds, built of stones and mud, with layers of sticks at intervals. The rooms in them, occupied by the defenders, are at a considerable height above the ground, and often can only be reached by climbing up a rope hanging down through a shaft, not much larger than an ordinary chimney and quite as dark; a path to glory eminently unattractive. The demolition of these towers was reduced by us to an exact science, small parties of native sappers, properly equipped, being always kept in readiness to set out with every expedition, the effacement of each tower being always completed in an hour from commencement of work. On one occasion, there being no Bickford's fuze available, the havildar (or native sergeant) in charge of the party made an excellent slow match by tearing his turban into shreds, and rubbing damp powder into it. The demolition was completed in the usual time.

On the retirement of the force from the Khyber line to India in 1879, about 900 tons of stores were sent down the Cabul river from Jelalabad to Dakka, a distance of 40 miles, on rafts constructed some of timber and barrels, but the majority of tanned bullock hides, of which over 7,000 were used, the buoyancy of each being about 200lbs., and the average number of skins required for each raft being 36. These skins could be obtained in great numbers in all the villages near the river, and when sewn up and inflated by breath or bellows, were formed into piers like barrels.

THE SOUDAN, 1884–85.

The "zeriba," which so often played a prominent part in this campaign, was simply an enclosure surrounded by the thorny bushes of the mimosa, cut down and laid in rows to form an obstacle. In the branches wire was intertwined, when procurable, and a fair protection was afforded by the thorns against stealthy night attack, though there were not wanting instances of their being powerless to repel a determined rush. Barbed wire would probably make the obstacle much more formidable.

Land mines, fired both by electricity and by tread, were much used about Suakin. The Arabs seem to have been particularly dexterous in neutralizing the action of the former by cutting the wires, their movements being noiseless and impossible to detect, while drifting sand much discounted the utility of the latter, though had a hostile rush been made over them, they would doubtless have proved very effective.

The necessity for forming defences rapidly, and the evils of being interrupted when at work, cannot be more forcibly illustrated than by the action at Tofrik, familiarly known as the attack on "McNeill's zeriba."

At 7 a.m. on the 22nd of March, 1885, a formidable, if somewhat motley array marched out of Suakin, and proceeded across the desert in a south-westerly direction. The object of the expedition was to form an advanced post or depôt on the road to Tamai, on which an attack was meditated, and the composition of the force was as follows:—

1 squadron 5th Lancers.
A detachment of bluejackets with 4 Gardiner guns.
The 17th Field Company, R.E., with a section of the telegraph troop.
The Berkshire Regiment.
A battalion Royal Marines.

1 company Madras Sappers. The 15th Sikhs. The 17th Bengal Native Infantry. The 28th Bombay " "	Indian contingent.

But besides these fighting men, there was an immense body of non-combatants, or "followers," employed in looking after the 1,400 transport animals, camels, mules, etc., laden with food, water, and ammunition, and also a number of water carts. Even in an open country, a force thus hampered could hardly be expected to manœuvre with celerity, but when crossing a plain covered with a thick scrub of thorny bushes, and with small parties of the enemy being constantly seen by the cavalry scouts, it can readily be understood why the rate of advance did not average more than 1½ miles per hour. So at 10.30 a.m. the force halted at a clearing named Tofrik, and proceeded to trace out and construct three zeribas as previousl planned, one capable of containing 2,000 camels, and two others t flank it, each large enough to hold one battalion, the cavalry bein thrown out as vedettes into the surrounding bush. The southern zerib was told off to the Berkshire Regiment, and the other to the Marine Each was furnished with two Gardiner guns, and the large centr square was to contain the stores. The position which the troop occupied at 2.30 p.m. is shown in the drawing (*Plate* IV.), the India brigade being formed up in three sides of a square, acting as covering party. The bush to the north being denser than that o the south, two companies of the 17th Bengal Native Infantry wer marched across to the right of the Bombay Regiment, to prolon their face and to cover the parties working at the northern zeriba The transport animals were led into the central square, unloade and taken out again, and a large number of men were out on al sides cutting and drawing in bushes, while the Indian covering parties stood easy in line, but with bayonets fixed and ammunitio loose in their ball-bags. The space behind the 17th Bengal Nativ Infantry was filled with baggage animals, and a half-battalion of the Berkshire Regiment were having their dinner to the east of the zeribas, and about 250 yards from them.

The first alarm was given by an orderly, who reported that the enemy was advancing rapidly from the front, and Sir John McNeill had barely time to give the order for the working parties to be called in when the lancer outposts came galloping in, mixed up with the Arabs, who, to the number of 5,000, rushed on our troops in disorganized masses. The two companies on the right of the 17th Bengal Native Infantry were thrown into confusion by the cavalry riding through them, and the remainder of the regiment broke and made for the zeribas, after firing a volley, which did not check the onslaught of the enemy for a second. To make the dire confusion worse, the Arabs stampeded all the transport animals and drove them also on to the central and southern enclosures, into which the savages swarmed, stabbing and cutting everywhere. The bushes interlaced with wire, contrary to expectation, did not seem to stop them for a moment, and on the south side matters assumed a very critical aspect. The brunt of the fighting naturally fell to the occupants of the Berkshire zeriba, into which the enemy poured over the fence and the sandbag parapet at the south-west angle. The Gardiner guns jammed and could not be got into action, and the naval detachment in charge of them were nearly all killed or wounded, but the right half battalion of the Berkshire Regiment and the Madras Sappers, who were at work outside, after getting to their arms, which were piled inside the enclosure, made a most gallant resistance, and 112 Arabs were afterwards found dead inside the zeriba. The official account mentions that two soldiers of the Berkshire Regiment were saved from certain death by the magnificent daring of Subadar Goordit Sing, of the 15th Sikhs, who, placing himself between the pursuers and their prey, killed three Arabs in succession by three rapid sword cuts. It omits, however, to narrate that he broke his sword by the last blow, a mishap which doubtless prevented a still more productive display from being recorded. In the meantime, all the other sides were enveloped and vigorously attacked, especially the 15th Sikhs, in front of whose position hundreds of dead bodies were afterwards counted; but at no point did the enemy succeed in piercing the line, so that after a few minutes all the assailants were shot down or dispersed. The left half battalion of the Berkshire Regiment, who were thus rudely disturbed while at dinner outside the zeribas, formed rallying square and repelled two successive attacks without suffering any loss, and killing over 200 Arabs. The first shot was fired at 10 minutes to 3, and at 10 minutes past 3 Sir John McNeill gave the order to "cease fire," and in that short time 1,500 Arabs were killed. But the victory was dearly purchased, 10 officers, 72 British and 61 Indian soldiers being killed, and a proportionally large number wounded. But the carnage amongst the wretched followers was terrible, 33 being killed and 19 wounded, while no less than 124 figure under the ominous heading of "missing." These were men who attempted to escape into Suakin, but were pursued and killed without resistance. It is also possible that the British troops, unaccustomed to fine distinctions between the natives of India and those of Africa, occasionally mistook panic-stricken fugitives approaching the zeriba for Arabs advancing with hostile intent. However, this lamentable slaughter of defenceless men forms to this day, in the Indian bazaars, a never-failing topic of conversation amongst the classes from which dooley-bearers, camel-drivers, and the like are enlisted. Even the unfortunate baggage animals fared no better than their owners, no fewer than 501 camels being reported as dead or missing.

TONGKING.

The French operations in Tongking and Annam, extending from 1882 to 1886, afforded many incidents worthy of consideration.

The French, on the one hand, though deficient in cavalry, and still more so in engineers, were thoroughly equipped with modern arms and appliances, while the Chinese, though meriting the epithet "savage" by their behaviour to wounded and prisoners, whom they invariably decapitated, often showed themselves sufficiently enlightened in the art of war. They exhibited all the skill in throwing up earthworks, for which they have been famous for centuries, nor did they allow the merits of the bamboo, as a war material, to pass without recognition. Besides the more ordinary *rôle* of spikes, fraises, palisades, and *chevaux de frise*, the bamboo was frequently called upon to play the more ambitious part of spar bridge, scaling ladder, and even field observatory. Strong works were numerous in the country, some with masonry escarp walls, others constructed of mud bricks, carefully trimmed, and built up like masonry, bound together inside by spikes of bamboo, the slopes being revetted with mats made of split bamboo. The coast defences were often very formidable, mounting heavy guns, and defending channels strewn with submarine mines; and where it was deemed advisable to close a passage that might prove advantageous to the advance of the enemy, junks full of stones were promptly sunk in it. The Celestials were doubtless much indebted to European officers for the excellence of their works, those of Foochow, for example, having been built by a French Engineer.

The attack upon the arsenal of this place by the French fleet is worthy of special mention. The town itself, which was of great importance as containing an arsenal and dockyard, was situated on the river Min, about 35 miles from its mouth, the navigation being somewhat difficult owing to shifting sandbanks and intricate channels. The defence of the river consisted of several groups of works, well placed to defend the channel, some being old batteries armed with antiquated weapons, others of modern type with large Krupp guns, some casemated and others open. Besides these, 11 powerfully-armed gunboats of the Chinese fleet were anchored close to the arsenal. Nothing could have been more interesting and instructive to posterity than an attempt made by the French fleet to force its way up to Foochow in the face of this defence. The question of "Ships *versus* Forts" would have been supplied with statistics which at present it sorely lacks. But Admiral Courbet, who commanded the strong French squadron, by a so-called *ruse de guerre*, the probity of which is open to question, reduced the intricate problem to an assault, unscientific and one-sided. Trusting to the existing treaty of peace, he succeeded in arriving at the Pagoda anchorage without molestation, and then declaring hostilities, he first destroyed the Chinese ships, and afterwards the river works in detail, attacking them from above as he fell down with the stream, and as most of the shore guns had not been mounted so that they could fire up the river, there was little or no defence.

This tale contains a useful lesson for those whose duty it is to design our coast batteries.

THE SIEGE OF TUYENKWANG.

Here is presented to us the phenomenon, absolutely unique, of a European force, hemmed in by a horde of savages, who had recourse to the most elaborate siege operations, and actually succeeded at getting into the work thereby (*Plate* V.). The citadel of Tuyenkwang is a square of 300 mètres side, bounded on the east side by the river Clear, and commanded by high ground, within short range, on the other three. It was surrounded by an earthen parapet, supported by an exposed escarp wall of masonry, about 11 feet high, while in front was a bamboo palisade standing in the open. The garrison of 600 men, under Commandant Dominé, possessed two field, two mountain, and two Hotchkiss Q.F. guns, the gunboat *Mitrailleuse*, with one heavy and one Q.F. gun, and a crew of 25 men, being anchored opposite the East Gate.

A state of siege was declared on the 24th November, 1884, and the garrison was beleaguered till the 3rd March, 1885, when they were relieved by a large force from Hanoi. The besieging force, which was said to number 20,000 men, made up partly by Chinese regulars and partly by Tongkingese irregulars or "Black Flags," seem to have closely invested the place about the middle of December, and after a month of desultory attacks on the French outworks, a parallel was opened, on the night of the 21st January, behind a belt of trees. Large working parties were employed, branches of trees, fascines and bundles of straw being freely used, and the advance pushed on, partly by trenchwork and partly by sap, under cover of a heavy fire from guns of position and mortars, until, on the 1st February, the Chinese were only 250 mètres away from the south wall, while next night a parallel was established on the rising ground only from 50 to 100 mètres from the west face; and on the night of the 6th the assailants tunnelled under the bamboo palisade in front of the wall, and actually succeeded in placing a wooden roof, or shelter, against the escarp. This, however, when the moon rose, was detected, and pulled away with a long hook by a sapper sergeant, who seems to have been the leading spirit in the defence, until he received a wound, which proved fatal on the 18th February. The rapid advance of the Chinese trenches seems to have been due to the fact that, owing to the want of an electric search light, the defenders could not interfere much with their construction at night. When the attack approached the foot of the wall, small fascines, soaked in spirits and set on fire, were thrown down to illuminate the scene of action, and each sentry on the wall was provided with a movable machicoulis, which could be placed on the south wall to afford cover over any point where an attempt might be made to work. On the 8th February it became evident, from the heaps of fresh earth which were observed to be accumulating at the end of each trench, that mining was being attempted, so counter-mining was started by the garrison to neutralize it, and detailed orders issued for the distribution of the garrison, and the crowning and retrenchment of the breach in the event of the escarp being blown in. This actually was accomplished on the morning of the 12th, and was followed by an attack on the breach, which, however, was easily repulsed. Several other breaches were made before the place was relieved on the 3rd March, and in all seven assaults were delivered, in two of which the Chinese succeeded in penetrating the citadel before they were repulsed.

Great credit must be given to the garrison for their admirable defence. They had held out for 18 days after the opening of the first breach, and had inflicted great loss on the enemy. Working parties of infantry, under the direction of a sergeant of Engineers and seven sappers, were employed continuously day and night, their numbers being only limited by the supply of tools. Tents were torn up and converted into sandbags, and extensive works of retrenchment and defilade alone rendered the position tenable. But little damage seems to have been done to the walls by the Chinese artillery, but that may be accounted for by their indifferent shooting, and by the proximity of their guns to the ramparts, which enabled the French marksmen to shoot down the gunners through the embrasures as long as daylight permitted.

It must be noted that the Chinese were either ignorant or disdainful of the text-book dictum that it is impossible for saps to advance in the face of the fire of Q.F. guns, and, as a matter of fact, the reverse was proved. The Celestials, contrary to the custom of most savages in like cases, used to prelude their night assaults by much shouting and the sounding of horns and trumpets, a practice which, though doubtless inspiriting, is not to be commended, as proving an excellent advertisement of the intentions, as well as a fair indication of the numbers and position, of the attacking party.

THE FRENCH IN ALGERIA.

From 1830, the date of the capture of Algeria by the French, up to almost the present day, desultory fighting has been going on between them and the Arab tribes around, and though, of course, the discipline of civilization generally prevailed there were occasions when the French suffered disaster. Great barbarity seems to have been displayed by the Arabs, and the French sometimes showed themselves not very far behind in retaliation. Once five hundred Arabs, shut up in a cave, were burnt alive, and often in the excitement of hand-to-hand fighting, nice discrimination between men, women and children appears not to have been observed. England was at one time very jealous of France's success in colonization, and so one is not surprised when French writers gravely chronicle mysterious assistance afforded by us, even when all communication with the outer world was impossible.

The various campaigns are well worth studying by officers going to India. Flying columns of varying strength were perpetually being launched against native strongholds with the usual accompaniments of loss from climate and want of water. The roads being bad, carts had to be given up for pack animals, while the order of march was always as follows:—In front the advanced column of fighting men solely, closely followed by the main body, with baggage animals, ammunition, ambulance and stores; these, of course, regulating the pace of the advance. A small detachment of sappers accompany the leading column, to clear the way, their tools being carried on two or three mules, the remainder of the sappers and tools being with the main body. When working parties of infantry are employed, the *same men* are always chosen, and their packs carried on mules, the relief thus afforded always making this service very popular.

The following system of clearing the road is laid down:—An Engineer officer marches at the head of the column, accompanied by two men, one carrying charges of dynamite, and 10 pieces of Bickford's fuze, half a yard long, attached to detonators, and ready to fire; the other man the means of lighting the fuze (a box of fuzees is best), and some clay for covering the charge. In front and on both flanks march three other men at a certain fixed distance from the officer, their duty being to halt when he does, and to prevent anyone approaching him within the dangerous zone. Behind, at a safe distance, comes a small working party under a sergeant.

If an impediment be encountered which can be removed without the use of explosives, it is pointed out to the sergeant, who detaches some of his men to attend to it, and the march is not interrupted. If, however, it is necessary to use dynamite, the charge is placed, fixed and covered with clay. The officer sees that the men in front, rear, and both flanks, have kept the coast clear, fires the charges, and runs with his two assistants towards the front. The firing operation takes three minutes from the moment of arrival, and the clearing away of the *débris* by the sergeant and his detachment is generally effected sufficiently quickly to allow of the march being continued after a halt of less than a quarter of an hour.

The extreme rapidity and suddenness with which floods present themselves in tropical climates may be impressed on the mind by the following narrative:—In April, 1892, a detachment encamped for the night in a dry watercourse on the road between Tuggerth and Biskra. A violent storm, 35 miles away, filled up the basin which supplied the river, and caused such a flood during the night that the men, roused from sleep, had barely time to jump on the mules and escape, leaving everything behind. After 36 hours the flood went down as quickly as it rose, but vehicles, equipment and stores had to be dug out of a layer of mud and *débris* 5 feet deep.

Excellent orders have been formulated with reference to the fording of rivers, and the following may be deemed worthy of notice:—

When reconnoitring do not conclude, when a path runs down to a river, that there must be a ford there. If you do not see a corresponding path on the opposite bank, you will know that the approach is simply used by the natives for watering their cattle.

Cut away the banks and form ramps on both sides, making the roadway where the river is entered of extra width, to allow of space, in case of mules refusing and loads being thrown off. On the other side tell off two men at least whose duty will be to keep throwing sand or gravel on the ramp. Without this precaution the ground will quickly become a quagmire from the water dripping off man and beast, and locomotion may be impeded.

When crossing, the section must not follow one another so closely as to bank up the water, though, of course, each man will hold on to those alongside him for mutual stability. Especial care should be taken in getting the hospital arrangements across.

At night light a big fire on each bank to mark the ford. The men should be warned not to look at the water, as the practice produces giddiness.

An illustration is given of a rapid system of filtering by means of a blanket fastened to three pickets, while a stone thrown into it causes it to act as a funnel (*Plate* VI. *Fig.* 4). The corners of the blankets are tied round pebbles, which prevent them from slipping.

The villages, like some in Afghanistan, are surrounded by gardens, stone walls and irrigation channels, are very formidable, and not only defied direct and flank attacks, but occasionally necessitated a regular siege. A detailed account of the attack of Zaatcha, in 1849, is given in Brackenbury's *Handbook of Field Works.* After frequent attacks by the French on the walls and ditches of the village had been repulsed, recourse was had to the most classic procedures of siege warfare, sapping, passage of the ditch, and breaching by mining being replied to by destroying the head of the sap, flooding the ditches, and the retrenchment of the breach. After 52 days the place was taken, but not till great loss had been sustained by the French, who had 10,000 men on the spot. Over 3,000lb. of gunpowder was expended in demolitions.

The Arabs, more audacious and agile than their opponents, though they occasionally tried open attacks, generally dealt in surprises, and especially excelled in burning in doors, and smoking out the defenders.

The capture of the caravanserai of La Rahoüia, in 1864, amply demonstrates the necessity for preserving intact one's flank defence (*Plate* VI. *Fig.* 5). The bastions of the southern face, through which the main entrance passed, had some years before shown signs of weakness, owing to the growth of interior buildings placed against them. Buttresses (*c.c* in *Fig.*) were built in such a way as to screen the face of the bastions from the fire of the flanks. After a fierce struggle the assailant succeeded in piercing the walls at these undefended points, and the defenders were forced to retire into the bastion of the opposite face. When they got there, however, they found that the Arabs had taken advantage of their absence from these bastions, during the attack on the others, to block up the loopholes with logs, and to set fire to stacks of straw round them. So, blinded by smoke and exhausted by fighting for 12 hours on end, the unfortunate Frenchmen were obliged to succumb to superior numbers.

In conclusion, may I point out the drawing of a fougasse (*Plate* VI., *Fig.* 6), consisting of a trench of simple triangular section, with charges of dynamite (300gr.) laid at 2-mètre intervals along the bottom. This was tried with success at Montpellier, and recommended for use against the Arabs.

BURMAH, 1885, AND FOR SEVERAL SUCCESSIVE YEARS.

When the expeditionary force under General, now Sir Harry, Prendergast, V.C, K.C.B., R.E., steamed up the Irrawaddy to take Mandalay, considerable opposition was encountered at Min Gyan, about 80 miles below Mandalay. There the enemy had taken up a strong position on the bank commanding the river, and entrenched themselves strongly. Rifle pits and sunken batteries had been made, the latter armed with smooth-bore guns, and one Whitworth field piece, firing through long embrasures, which were directed on the channels through which the steamers had to approach. Perfect invisibility was obtained by design, and great care was taken that no sign of work should be left, the earth being carried away in baskets and thrown into the river. The accompanying drawings are taken from a paper by Major Fullerton, R.E., which appeared in the *R.E. Journal* (*Plate* VI., *Fig.* 3). These works were bombarded for hours by 40-pr. guns and 6·2-inch howitzers, but the effect on the works was *nil*, and nobody appears to have been killed. The moral effect, however, exceeded all expectations, as the Burmese evacuated the place, while the sound of the firing, which was heard at Mandalay, 40 miles off, is said to have frightened King Theebaw into surrendering, which he did next day, without firing a shot.

The desultory fighting which succeeded the capture of Mandalay has furnished many opportunities for the display of individual self-reliance and resource. In a war where long marches through thick jungle are necessary, where the isolation of small bodies of troops is more the rule than the exception, and where the inhabitants of the country alternately pose as friendly villagers and bloodthirsty dacoits, skilful in ambuscade, lessons in strategy and tactics are readily learnt by officers even of the most junior standing.

As most of the attacks made by the Burmese on our posts took place during their construction, it was imperative that the defences should be of a simple nature, and take as little time in completion as possible. The drawing shows a fort of a type much used, as requiring few night sentries (*Plate* VII.). It is described by Colonel A. Dorward, R.E., in a Corps *Occasional Paper*. As a protection against fire, and as a sanitary necessity, the buildings were always placed far apart, the result being that the length of the parapet was out of all proportion to the garrison, which generally varied from 50 to 500 rifles. It will be observed that the fire from the block-houses sweeps not only the ground outside and within the parapet, but also the whole of the ditch as well, while the idea of placing lamps at the distant angles seems eminently praiseworthy. The materials used for the construction of these posts were earth, bamboos, jungle wood, giant grass, and thorns of great ferocity. The commonest thorns in Burmah are sharply curved, and resemble the "Wait a bit" of Africa. They form the common defence of almost every village in Upper Burmah, and are particularly obnoxious to the dacoits, whose flowing garments and loose slippers are sure to get inextricably hooked up in them.

A section of a stockade is shown (*Plate* VIII., *Fig.* 1), made of earth, bamboos and thorns, there being no revetments whatever, a desideratum in a country where the rain is so heavy as to wash earth through hurdles made of split bamboo. It was at first thought that the thorns behind the parapet would catch fire from the flashes of the rifles of the defenders, but they never did, though they burnt readily when set fire to and dry. The bamboo spikes, which are about 9 inches or 1 foot long, are placed about 6 inches apart, with half their length stuck in the ground. When sharply pointed and charred their existence cannot be ignored even by the wearer of the sturdy ammunition boots, and they would, indeed, be most useful in any campaign, as they can easily be carried in bundles, and while formidable to men are destruction to horses. A few strands of barbed wire in the upper part of the bamboo stockade greatly increases its value as an obstacle.

Fascines, about 18 feet long and 10 inches in diameter, were constructed with river grass and mud (*Plate* VIII., *Fig.* 2). They were most useful for permanent revetments, and when properly made were so hard and tough that it was difficult to drive a picket into them. The grass would grow into the parapet if watered, even when the latter consisted of pure sand, and in a short time the fascine or roller would be firmly knit into it.

An excellent spiked palisade of bamboos was made of stout uprights with horizontal pieces lashed between (*Plate* VI., *Fig.* 2). Between these, spikes were forced into the required position, as shown. It will be seen that it was impossible to get at the uprights till the projecting spikes had been cut away.

As an example of what junior officers were occasionally called upon to do, I will now refer to the attack made on the fortified post of Sadon in February, 1892, as described by Lieut. MacMunn, R.A., now D.S.O., in the R.A. Institution papers.

Sadon was a village of the Kachins, situated about 100 miles north of Bhamo, our most advanced military post up the Irrawaddy, and only 12 miles from the Chinese frontier. It was 4,500 feet above sea level, and had been taken early in 1892 by a strong column, which, however, marched out of it on the 5th to raid some distant villages, leaving behind a small force under Lieutenant Harrison, R.E., now D.S.O. It consisted of 7 invalid Europeans, 20 Goorkhas, of whom 12 were invalids, 48 Burmah Sappers, 50 men of the 3rd Burmah Regiment, and 50 Madras Infantry, under Lieutenant Perry, and the orders were to work hard at completing the fortification of a post which had been commenced on a hill 600 feet above the village. It consisted of a stockade of young saplings about 6 inches diameter, with bamboo spikes, and a small ditch, but on the 5th it was in a very unfinished state, the jungle having been cleared away for only about 80 yards round the fort.

On the 6th of February Lieutenant Harrison received visits of ceremony from the headmen of the surrounding villages, and compliments were exchanged; but during the evening crowds of men were seen pouring into Sadon, and the garrison were ordered into the post, which was duly attacked next day by 700 or 800 Kachins armed with matchlocks, Tower muskets, and a few rifles, three men being wounded. The place was regularly surrounded, and a heavy and continuous fire was kept up day and night from the surrounding jungle.

The weak spot in the defence was the want of water, which had to be carried from two springs, one 250 yards distant and the other 400 yards. The site seems not to have been above reproach, in that the inside of the work rose above the level of the terreplein of the stockade, and was swept by the enemy's bullets. Ration bags were filled with sand, impromptu gabions made, precautions taken against fire, and the flanking tambours strengthened with kit bags, etc.

When it was necessary to sally out to obtain water, it was found that the enemy had stockaded themselves in the vicinity of the wells. In front of the stockades they had placed *chevaux de frises*, and had actually manufactured gabions and fascines of great excellence and neatness.

On the 9th, no less than 10 stockades had to be captured and destroyed; but in the evening, to the surprise of all, a welcome reinforcement appeared in the shape of Lieutenant MacMunn, R.A., with 1 native officer and 12 men of the Goorkha Mounted Infantry, who had been sent up from down country with a convoy of rum, under the impression that all was in a state of profound peace. They had been fighting all day, but managed to get through with the loss of Lieutenant MacMunn, the native officer, and two men wounded, all the kits and most of the rum having disappeared *en route*. The enemy kept up their fire all through the night of the 10th, and in the early morning tried to rush the north-east gate, actually getting so close as to pull out some of the bamboo spikes. A successful sortie was made on the 12th for water, enough for four days being brought in and stored in tanks made by digging holes in the ground and laying waterproof sheets in them. As all the hand grenades were now exhausted, bombs were made out of empty jam and marmalade tins, with a guncotton primer inside, packed with sand and stones, with 6 inches of Bickford's fuze attached. The investment was maintained, and attacks made daily. Arrows with coils of sulphur round them were shot into the work, to set the roofs on fire. On the other hand, Lieutenant MacMunn constructed a gun of bamboo. It was of 3-inch calibre, 2 feet long, bound round at muzzle and breach with wire, covered with splints of wood, and the whole fastened together with cord. This fired a shell 6 inches long, also made of bamboo, and is said by its author "to have impressed the Kachins," who, however, nothing daunted, started a sap at a distance of 180 yards, and also bombarded the post with a jingal (or sort of wall piece), which, however, produced but little effect. This was the less surprising, as the Kachins, relying on the effect of sound, chiefly fired it with blank cartridge. In one of the sorties one of the garrison by accident trod on a pangi, or bamboo spike, which went through the sole of his boot and foot and came out at the top.

On the 20th the main column returned, and caused the siege to be raised; but as the place had held out, under three young subalterns, against continuous attack for 14 days and nights, and had suffered a loss of 6 men killed and 27 wounded (including 1 English and 2 native officers), you will agree with me in considering the performance well worthy of record.

STANLEY'S EXPEDITION IN CENTRAL AFRICA, 1887–89.

The following description of obstacles encountered was given by the late Lieut. Stairs, R.E., in the *R.E. Journal*, and may be interest in showing the diabolical skill of the forest natives an dwarfs in constructing them, the cunning way in which they wer concealed, the deadly poison used in connection with them, and th patience and care employed in perfecting them (*Plate* IX.).

Fig. 1.—Poisoned stakes sharpened to the fineness of a needl and charred in a slow fire, sunk in a small pit dug on the path alon which the enemy is expected to arrive. Leaves and sticks ar placed over the holes to hide the stakes.

Fig. 2.—Short poisoned stakes placed on the top of a log lyin in the track, and longer ones in the ground beyond it. Th commonest way of getting over an obstacle of this sort is to plac one hand on the top and vault over. The spikes are thus calculate to pierce both hand and feet.

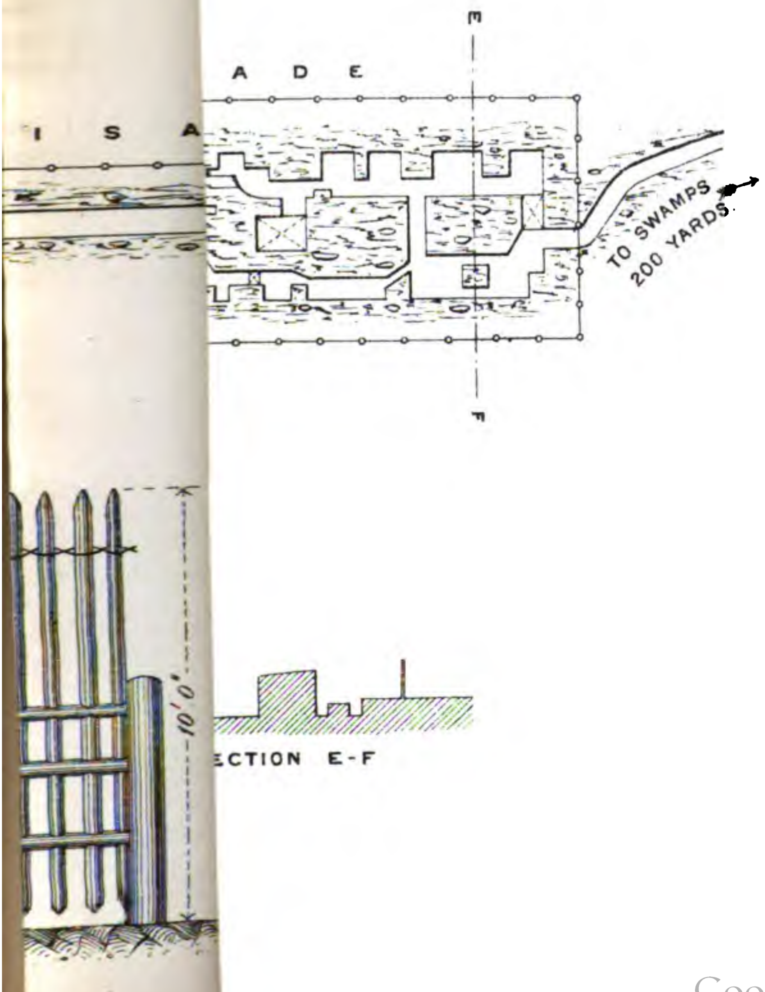
Fig. 3.—Long poisoned stakes driven into the ground at a angle of about 30, and hidden in long grass. The idea is that the point should enter the stomach of anyone who approaches hastily, and then snap off.

Fig. 4.—Stakes, which have been discoloured by smoke to render them less visible, placed in the bed of a stream, and likely to penetrate the legs of anyone who tries to cross.

To guard against these ferocious obstacles, men skilled in woodcraft, and understanding the subtleties of the natives, should be sent on ahead of the advanced guard, well provided with sandals, and with their legs bound up as high as their knees with strips of bullock hide.

In conclusion, it is hoped that the few points which we have now considered may induce some young officers to take up for themselves the study of our minor campaigns, which cannot fail to be both interesting and profitable. Our small wars follow one another with great rapidity, and incidents in them are quickly forgotten, but if anything that I have said will induce any of you to unearth and investigate some of our half-buried military histories, then the object of this lecture will have been accomplished.

PLATE I.

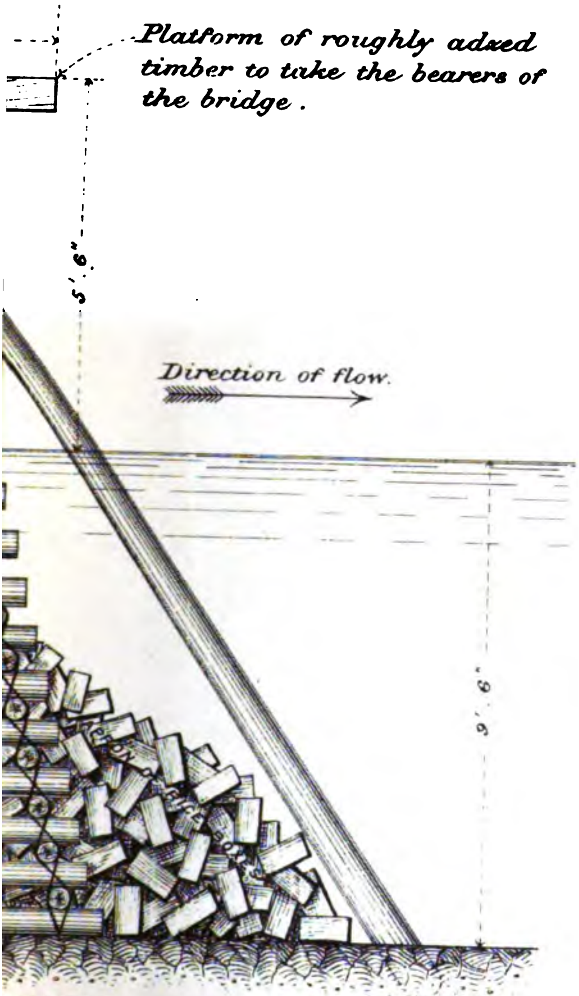


PIER.

AGE WARFARE.

PLATE II.

DGE ACROSS THE PRAH.

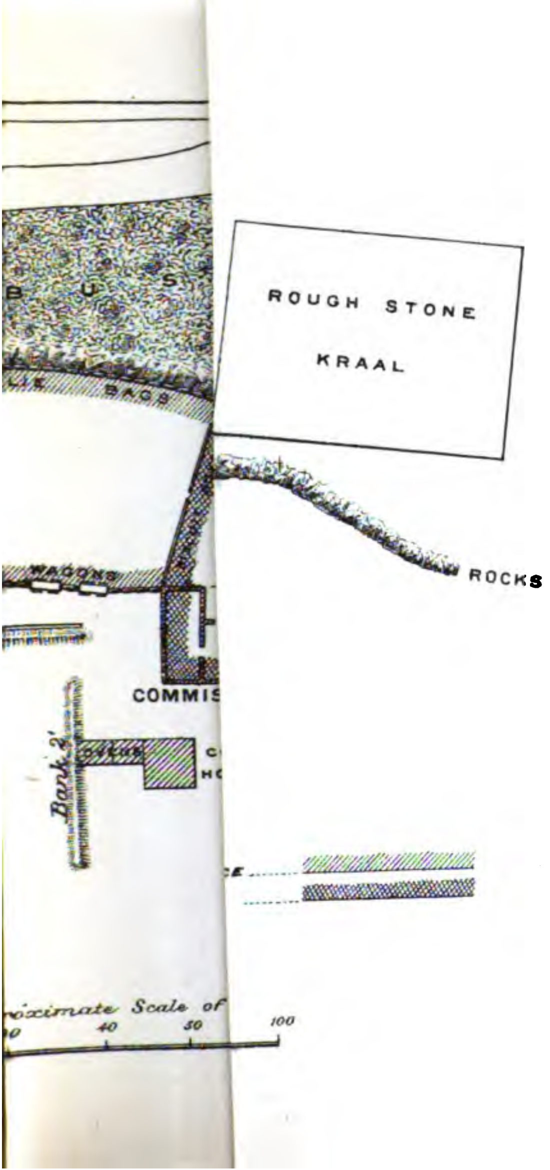


Platform of roughly adzed timber to take the bearers of the bridge.

PIER.

IN SAVE.   PLATE III.

OF RORKE



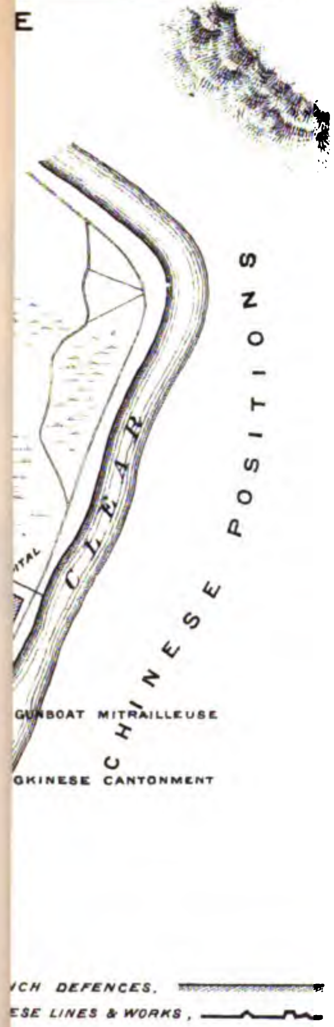
RFARE. **PLATE IV.**

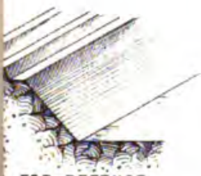
A.

I.

WARFARE. PLATE V.

E





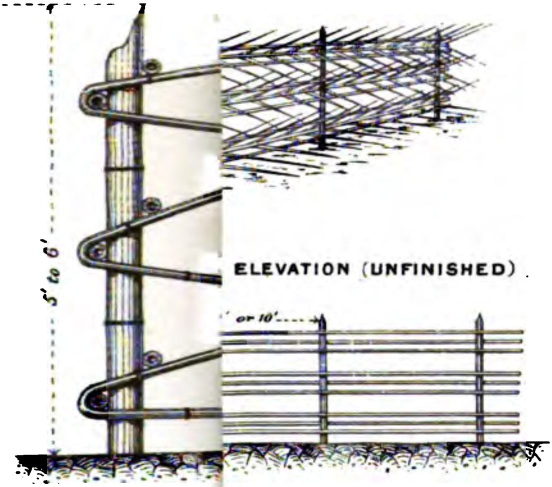
FOR DEFENCE

SAVA

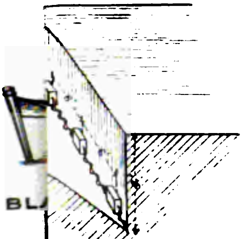
PLATE VI.

SADE. Fig. 2.

SRONT VIEW.



ELEVATION (UNFINISHED).

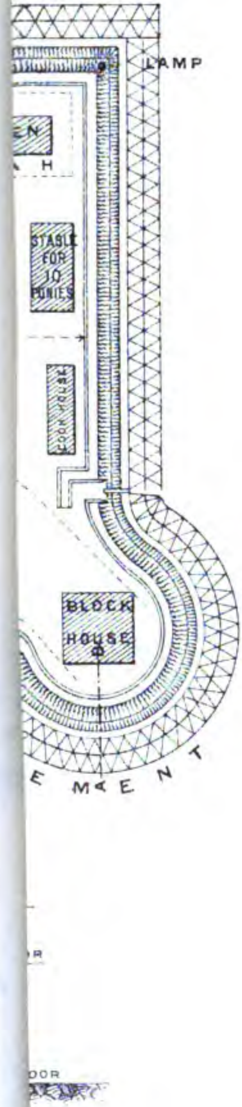


FOUGASSE. Fig. 6.

PLATE VII.

WARFARE.

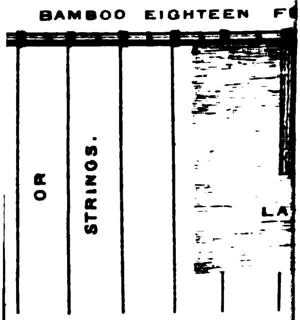
N BURMA.



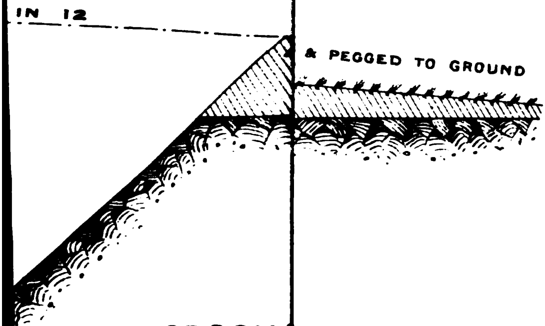
TION IN

PLATE VIII.

LE MILITARY



RUCTION OF GRASS R



OUGH STOCK

AGE WAR

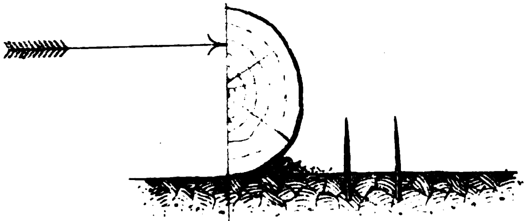
PLATE IX.

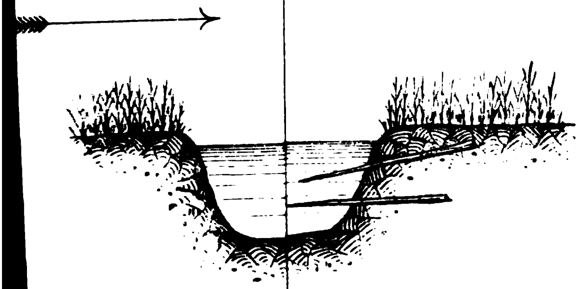
TRAL AFRICA.

S.

of advance.

2.





PAPER VII.

THE DESIGN OF SOLDIERS' BARRACKS.

BY MAJOR SCOTT-MONCRIEFF, R.E., A.I.C.E.

ANITARY science has of recent years made many notable changes n the design of houses for all classes of the community. In towns the tendency is, wherever possible, to build in rows of villas, either separate or semi-detached; in crowded streets, where such independence is not possible, recent legislation has decided what shall be the limits of interference with light which the mass or bulk of one building shall present to the windows of another.

The *tendency* is in the direction of more room, more sunlight, more attention to proper provisions of fresh air, good water supply, adequate sewerage. Not that disgraceful slums have yet been abolished from our cities. Vested interests are, unfortunately, still too strong, and the problem is intensely complex. The tendency, however, of modern legislation is in the direction of improvement, thanks to increased knowledge of sanitation.

This increased knowledge has had its effect in the design of recent barracks, and the improvement of those barracks which were built in days when ignorance prevailed alike in military and civil life.

In military life we are, fortunately, free from the incubus of passive obstruction which greed or love of gain presents to the sanitary reformer in many cases in civil life. We have, on the c trary, the assistance which public opinion in the service or Parliament always gives to any scheme or sensible suggestion improving the condition of the soldier, and we engineers invarial have with us the strongest support alike from the medical authorit and from generals in command.

The chief difficulty, as a rule, is

> "That eternal lack of pence,
> Which vexes public men."

But even in that respect there is generally, on the part of t financial authorities, more readily a disposition to be generous respect to sanitary questions than in many other matters.

It must be here premised that sanitary engineering does merely mean sewerage. It means a great deal more. It includ also, water supply and lighting, ventilation and warming of th dwellings within, free access of air and sunlight without; it includ proper provision for the cooking of food and ablution of the body. All these matters must be taken into account and combined before we can adequately consider the question of design.

In addition to all these the architect has to consider the questio of art and beauty in the work which he plans. In the suggestions made in this paper no question involving architectural adornment will be considered. The military engineer, who has not been trained to art, has to consider questions of economy in construction, that is to say, that, having a large number of similar buildings to construct, he must consider how he can produce his design with the least expenditure of material. A small extravagance of material will make but a trifling difference in a single building, but it will make a very appreciable amount when multiplied a hundred-fold.

Further, the engineer has to bear in mind military questions, *e.g.*, how discipline shall most easily be administered, how parades shall be carried out, and how tactical units shall be conserved.

The Army Sanitary Commission of 1863 decided that the design of a barrack should be simple, that the architect or engineer should endeavour to obtain a maximum of fresh air and sunlight on every part of the outer walls of a room occupied by human beings, and that, therefore, closed corners or re-entering angles should be avoided.

A plan of a barrack adopted as a type should be capable of such alterations as will, without change of general design, admit of its ing adapted to changes of site or climate. It would, obviously, contrary to common sense to build the same barrack, exact in ery respect, at Cork and at Aberdeen, or in a warm sunny valley, d the top of a ridge, such as that at Inverness, where the N.E. ind whistles across the Moray Frith. But the same *type* may be llowed if certain modifications be introduced suitable for the local rcumstances of the case.

A type plan should also be capable of extension, so as to suit the rger amount of cubic space required for warm climates.

Finally, and, perhaps, most important requisite of all, the type s to be adapted to the British soldier. One does not wish on the e hand to give the men unnecessary luxuries such as they are accustomed to in civil life; on the other hand, the wish of all ficers is to train the men in habits of cleanliness, self-respect and briety. The barrack must be designed to this end, so that it may easy for a man to be cleanly, in person as well as in outward pearance, and that he may have a reasonable amount of comfort his habitation. Much attention has of late been paid to soldiers' et, and, perhaps, a little study may, therefore, be devoted to his welling.

The object of this paper is to examine existing types and roposals, criticize them—in no unfriendly spirit, but with a desire or public advantage—and to make some suggestions which may ossibly, if not considered suitable themselves, lead to others of reater practical utility.

To recapitulate the necessary conditions :—

(*a*). The barrack must be sanitary as regards sewerage, surface drainage, water supply, light, air, ventilation, warming, access to ook-houses, *and these must apply not only to each single block, but to all in combination.*

(*b*). It must be economically designed.

(*c*). It must be adapted to military requirements.

(*d*). It must be as simple in design as possible.

(*e*). It must admit of small modifications to suit local requirements.

(*f*). It must be adapted to the wants of the soldier.

ALDERSHOT TYPE.

The type examined critically is that adopted in the Stanhope Lines at Aldershot, recently built. These barracks are two-storied, and built as shown in *Plate* I. A detailed plan is shown on *Plate* II., *Fig.* 1. The blocks run east and west, so that one side of block rarely gets any sunlight at all.

The accommodation is so arranged that in event of an unus number of men being absent, as may happen during the furlo season, the end portion or "hammer-head" may be closed entir During the period when the barrack is full, those men who liv the "hammer-head" must necessarily pass through the other ro to reach their own. Hence the other room becomes a thoroughf and the men who occupy it have more than their own share of d to clean. On the other hand, they are better off as regards th food than the occupants of the end, because they are a little nea the cook-house; although, in many blocks, the dinners must in eit case inevitably be cold, however elaborate the *menu*, by the ti they reach the barrack-rooms, for the cook-house is some dista away, and is not reached by a covered passage.

There are two cook-houses per battalion.

In this type of barrack the soldier sleeps and eats in the sa room. He has cupboards in which to keep eatables, but the fact keeping food in a sleeping room is condemned by medical experts bad for the food, and unwholesome for the sleeper.

The position of the urinal in this type of barrack is also noteworthy At the door of the barrack-room, in a very prominent position, a stand on which is placed the urine tub, long ago condemned b the Army Sanitary Commission, and to this day stigmatized b medical experts as an abomination. Night urinals, *i.e.*, small room leading out of barrack-rooms, locked during the day, open at night are to be found in many barracks, and are seldom in a sweet an wholesome condition. The improper use of these, doubtless influenced the arrangement now found in the Aldershot barracks a at least an evil of lesser magnitude than that obtaining in some barracks with permanent night urinals. The question of adequate convenience in this respect is undoubtedly difficult, yet (it is thought) not impossible to solve. On this subject more presently.

There is but one entrance and one staircase to the block, an obvious disadvantage.

The combination of buildings on *Plate* I. does not lend itself to simplicity of drainage, sewerage or water supply.

Latrine accommodation is provided in separate buildings from barracks. The latrines are flushed periodically at certain hours, generally once a day—not a pleasant arrangement.

Sufficient has been said to prove that this type, although an immense advance on the old huts which it replaced, is not such as will convince us that finality on the subject of the best design has been obtained in it.

MR. MARRABLE'S TYPE.

The next type to be considered is that shown on *Fig.* 2, *Plate* II., proposed by Mr. Marrable, District Surveyor, R.E. Civil Staff, in a paper entitled "What a Barrack Should Be to Meet the Requirements of the Age," published in *The Occasional Papers of the Association of Surveyors.*

He proposes to build three-storied barracks, and accommodate 100 privates on each floor in little rooms of 10 men each, leading off a large central corridor, which serves as dining hall. The cook-house, ablution room, latrines and urinals are brought under the same roof and the same floor, and he provides a sleeping room for four N.C. officers in another room, also on the same floor. There are also other conveniences allowed, such as company stores, pay offices, etc.

In examining this plan one cannot but be grateful to a member of the civil staff for having taken the trouble to work out a scheme of this nature. It has been most carefully considered, and must have involved much labour. At the same time, there are many very grave objections to it.

It offends the canon that the design should be simple. It would, if built, result in a large building, occupying much area, with many deep recesses or dead angles, where air would stagnate and sunshine never reach, and where the rooms would be dark by reason of bulk looming opposite to the windows.

The corridor or dining hall would be cheerless and draughty.

The urinals are, no doubt, under the same roof as the dormitories, but so far away that the men would not, in many cases, take the trouble to go to them, along cold and draughty passages.

The sergeants are too far away from their men to render efficient supervision, and the staircase accommodation in event of a sudden turn out, *e.g.*, in case of fire, is quite insufficient.

It is, however, easy to criticize, and especially easy to pick faults. It is not so easy to suggest a remedy.

S.M.E. TYPE.

In the type now submitted, shown on *Fig.* 3. *Plate* II. (where, for the purposes of comparison, the drawings are all represented to the same scale), the general arrangement is one which will be familiar to all officers who have served in India, although there the type is usually confined to single-storied buildings.

Endeavour has been made in this design to retain the best features of both the Aldershot and Mr. Marrable's suggestions, as well as the Indian type, and thus, by a process of evolution, obtain a type which will be an advance in the direction of general utility.

The two-storied company block, as in the Aldershot type, is retained, with four dormitories each for a "section," or one-fourth of a company. (For present purposes we may consider infantry only, and use terms applicable to that arm. The same principles apply, *mutatis mutandis*, to cavalry, artillery, or engineers). These section dormitories are separated on each floor by a transept, to be used as a day-room and dining-room (see *Plate* III. for details). It will, therefore, be possible to reduce the breadth of the dormitory to 18 feet, and give the men more space than now obtains between their beds, because as they will not have their meals in the barrack, all the width required will be for two rows of beds (say 13 feet) plus occasionally a barrack table (3 feet), and 1 foot on either side. Each man still has his 60 square feet of floor space or 600 cubic feet of air. Only a few tables and benches will be required in the dormitory, the rest being in the day-room; hence the cubic air space actually available will be greater than with the present arrangement.

The windows are arranged so as *not* to be opposite one another. The amount of light given is 1 square foot to about 100 cubic feet of interior accommodation. This may be altered, however, to suit circumstances.

Plate IV. shows a barrack for an infantry battalion arranged with all the blocks of this type, and giving proposed arrangement of sewers. The system is shown as the combined system of surface and foul water, because this is the most common system in barracks, but, of course, the separate system is easily substituted. It will be evident from this drawing how easily the type adapts itself to drainage.

As regards water supply, it is evident that a main can be taken up the street between two rows of barracks with branches, governed by stop-cocks, opposite each annexe, lavatory and cook-house. No cisterns will be necessary, except the small ones over the w.c.'s and the feeds to cook-house boilers. A continuous supply, governed by stop-cocks, and with proper meter regulation, may be entirely independent of cisterns, "ball-cocks and all the abominations of bungling plumbers" (as Mr. Frederic Harrison alliteratively remarks in his *Teaching of History*), to the great comfort of those who would otherwise find them hard frozen in a severe winter.

Gas is the usual illuminant used in barracks, and in its present application to the soldier's room it can hardly be said to be either wholesome, cheap or efficient. Among the many new inventions recently brought out it is difficult to say which is most suitable for the barrack-room, but possibly the Stott-Thorpe light, which combines brilliancy, economy and ventilation (by carrying off the products of combustion through the ceiling), will be most efficient. It is proposed to use it in this case.

Ventilation in this design would be partly ensured by the use of foul air shafts connected with chimneys. The Tobin's tube is probably the best form of inlet. Another extremely simple invention most suitable for barracks is the "Fenestra," where all cutting of the barrack wall is avoided, and a grating opened by a sliding door is given in the hollow boxing of double-hung window sashes. By using this for inlet and the gas for outlet shafts the ventilation in the barrack would probably be thoroughly carried out.

Warming is proposed to be effected by fireplaces with ventilating grates. Stoves would possibly be more efficient, but it is doubtful if the men would like them.

The plan of the cook-house, one of which would be given to every two companies, is shown on *Plate* III. It is arranged on the principle advocated by Brigade-Surgeon-Lieut.-Col. Evatt, in his lecture on "The Sanitary Care of the Soldier by his Officer,"* where a preparation room outside of the kitchen, and a scullery and a store are provided. In this cook-house there are baths for the men. The whole is connected by a covered passage with blocks on either side, and staircases lead to the dining-rooms on the upper floors.

The details of latrine and urinals here demand some attention. Recent inventions in pedestal closets are of a description which makes misuse of them almost impossible. They may be now-a-days formed of enamelled iron, with or without wooden seats, so as to be practically indestructible, and there seems no reason why a soldier should not have these provided for him, with water waste preventive cisterns, controlled by the user of the closet. Even if this be not approved, a range of seats with an automatic flushing apparatus, such as has been introduced with the greatest success into Chatham Dockyard by Messrs. Doulton, would be far better than the usual barrack latrine now used. As regards urinals, most railway stations have them with running water in a raised trough, and the same type might quite easily be introduced into barracks.

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* *R.A. Institution Proceedings*, May, 1894. Anybody who wishes to read straight, sensible talk about the soldier should get this. The dining-room question is there discussed, and no doubt expressed as to its advantage.

So much for condition (*a*), viz., sanitary design.

As regards (*b*)—economy—we have to consider not merely first cost, but repair. This consideration points to the desirability in many cases of using some other material than slates for the roof. Tiles are now manufactured as light, as durable, as non-absorbent, cheaper, and far prettier than slates. Only those who have had to keep in repair acres of slate roofs in a stormy winter know how grievously extravagant they are.

For the rest, the span of the roof makes a collar beam truss feasible, and the absence of complication in design makes the whole roof simple.

The floor may be either single or double, on steel joists, the latter for preference. The floor of the annexe should be of asphalte or tar concrete, as being pleasant to walk on and not absorbent.

The broad question of economy of the whole we shall discuss presently.

We now come to the condition (*c*)—military requirements. On this little need be said. The general design (*Plate* IV.) shows the arrangement of a battalion in wings on either side of a parade ground; the detailed plan (*Plate* III.) shows the sergeant's rooms near the company or section under his command. The design is, therefore, adapted to tactical units.

Each section room has a separate entrance and a separate staircase, its own ablution rooms, its own range of w.c.'s, and its own urinal. *For these the N.C.O. of the section must be primarily responsible*, subject, of course, to the daily supervision of officers and medical staff.

The only other matters which we have to consider now are whether the type is adapted to the ordinary wants of the soldier, and whether it is capable of slight modification. With regard to the first point, evidently if one can ensure greater comfort in meals,* decency in habits, and yet not interfere with discipline, an important point has been gained. Lord Wolseley says*: "We pay our men so wretchedly that we can only hope to entice men to enlist by making them happy whilst they are with us, and the first step towards happiness is to make men's dwellings bright and cheerful." In this type of barrack the windows open on the parade ground, or the outer country (see *Plate* IV.), not, as in the Aldershot type, on the next barrack. This is in itself not unimportant.

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* Some officers say they have tried dining-rooms, but have found that the men did not care for them. If the dining-rooms were a long way from the barrack-room, probably the men would not like them. If you put them close to the barrack-room and close to the cook-house it is quite another matter.

As regards alteration to suit various places, if the climate or site is very hot, a small verandah can easily be made on the sunny side of the block, between the dining-room and the sergeant's room. Or if the expense of a verandah be prohibitive, outside venetians can be applied to the windows. On the Continent these are universally applied to barracks. If the site is a cold one, increase the width and reduce the length of the dormitory, give fewer windows on the exposed side and thicken the walls. The type in neither case is altered.

But the question will probably be asked, "What about the expense of the whole as compared with the Aldershot type?" No doubt, at first sight, it appears as though the S.M.E. type must be the more expensive, on account of the extra accommodation provided, each half-company having its dining-room, and one-fourth of the cook-house instead of one-eighth. If we estimate the cost of the Aldershot block and the S.M.E. type, the latter will certainly be greater, but we have to take other matters also into consideration.

To adopt this type to regimental requirements (as in *Plate* IV.) we have to consider the accessories, the canteen, sergeants' mess, quartermaster's stores, etc., etc. These are shown generally on *Plate* IV., and in detail on *Plates* VI. and VII., each being based on the dimensions given in the Barrack Synopsis, and adapted to the general type, as will be seen by comparing the elevations in *Plates* III., VI., and VII.

Plate V. shows the accommodation for a brigade of four battalions on exactly the same acreage as that occupied by the 1st Infantry Brigade in the Stanhope Lines at Aldershot.

By comparing the areas occupied by the buildings in both cases we should get a fallacious result, inasmuch as several of the buildings in the Stanhope Lines are single-storied which are double-storied in the S.M.E. type. The actual plinth area in the former is about 366,000 square feet as against 346,000 in the latter.

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* As quoted by Brigade-Surgeon-Lieut.-Colonel Evatt in the lecture already alluded to.

The difference is caused by the large recreation establishments canteens and sergeants' messes provided in the Stanhope Lines. Those suggested in the S.M.E. type are in accordance with the Barrack Synopsis. That they are on a sufficient scale is not questioned. On the other hand, it has been asserted by some commanding officers that those of the Stanhope Lines are too large.

In any case, by bringing into a double-storied building the rooms now scattered over single-storied ones, we gain space and save roofing. Whether they are equally suitable is a matter of opinion; similar buildings in other places are considered quite suitable (*e.g.*, the R.A. canteen and sergeants' mess, Wellington Lines, Aldershot). The cost, however, can be ascertained approximately by cubing out the blocks and giving the same price per foot to each class. Thus the cost for a soldiers' barrack per foot cube may be reckoned at 5d., whereas officers' quarters and mess amount to about 1s.

On this basis the brigade of four battalions on the S.M.E. type would cost £236,000, and the Aldershot type £225,800, a difference of about £10,000, or about 4·5 per cent. This takes no account of any advantages gained in the S.M.E. type by simplicity of drainage, or any of the other points which may be put to the credit of this type.

It is believed that this extra percentage would be materially reduced in considering the types in detail.

At all events, it is a matter for consideration whether the advantages of the proposed type to the British soldier, and, therefore, indirectly to the nation, are worth an excess of 4½ per cent. on the cost of a new barrack.

MARRIED QUARTERS.

The improvement in the condition of the married quarters has, of recent years, been most marked. Instead of one room where a man, his wife, and a maximum of three children were obliged to live, eat and sleep in very questionable comfort, each quarter has now a kitchen and scullery, some have an additional bed-room, and some even have three living-rooms as well as kitchen and scullery. There are, however, here also certain disadvantages. *Plate* VIII. shows the present type plan of married quarter. It will be seen that the rooms are somewhat closely packed, the stairs in some cases being in the rooms. In many cases (though not in the latest type) there is no w.c. accommodation inside the building.

Medical officers tell one that however great an improvement these quarters are on what used to be the type, yet they are wanting in sanitary efficiency. It is cruel to force a delicate woman to use outside latrines, and many of them dislike it from motives of decency. Again, if baths are considered desirable for unmarried soldiers, why should the married soldier and his wife or child not have one also? If cleanliness is next to godliness the unfortunate barrack bairn has a very poor chance.

In the type proposed (*Plate* IX) both these sanitary defects are altered, the quarters are divided by passages, which, to a certain extent, isolate portions of the building. The chimneys are brought to the centre of the building, where they ought to be, and not scattered all over the roof. Lastly, but not by any means least in point of comfort, the water supply is continuous, laid on to each group of quarters from an outside main, and there are no huge cisterns overhead to cause misery in frosty weather, and involving girders and beams for their support. What the discomfort caused by these frozen cisterns was to the married soldier in the great frost of 1895 no words can depict.

All this is important. If we are to induce sober, respectable men to stay in our army, to be the backbone of our regiments, *i.e.*, the N.C. officers, we must make the married quarters decent, healthy and attractive.

WARRANT OFFICERS' QUARTERS.

We must also provide an attractive residence for the soldier when he reaches the highly honourable position of a warrant officer.

Plate X. shows the authorized type of a pair of such quarters. It will be noticed that one of these has an extra bedroom, that the living-room is large and the kitchen small, that there is a small back yard which interferes much with light (to say nothing of the outlook), and that the w.c. accommodation is outside.

These defects are remedied—at least, to a certain extent—in *Plate* XI., which gives a simpler type of building, with equal accommodation, and its internal arrangements better suited to the use of a man of that class and social position.

In making the above proposals nothing but what affects the soldier has been considered. Officers' quarters, troop stables, and the many auxiliary, accessory and subsidiary buildings involved in barracks have been left out of the question.

Unfortunately, in the Corps we have no such institution as the Aldershot Military Society or the R.A. Institution, where proposals can be discussed by the collective wisdom of officers of experience, and where heated enthusiasm is subject to the cooling effect of dispassionate criticism. It is, however, to be hoped that the proposals here made will be subjected to criticism, so that the weak points may be exposed. The elaboration of these proposals has not been the work of a few days nor a few weeks. The writer has been fortunate enough to obtain the views and suggestions of many warrant officers, N.C. officers and men, and has given full weight to their opinions; and he has been further able to bring to bear on the subject a personal experience of some of our largest military stations, both at home and in India.

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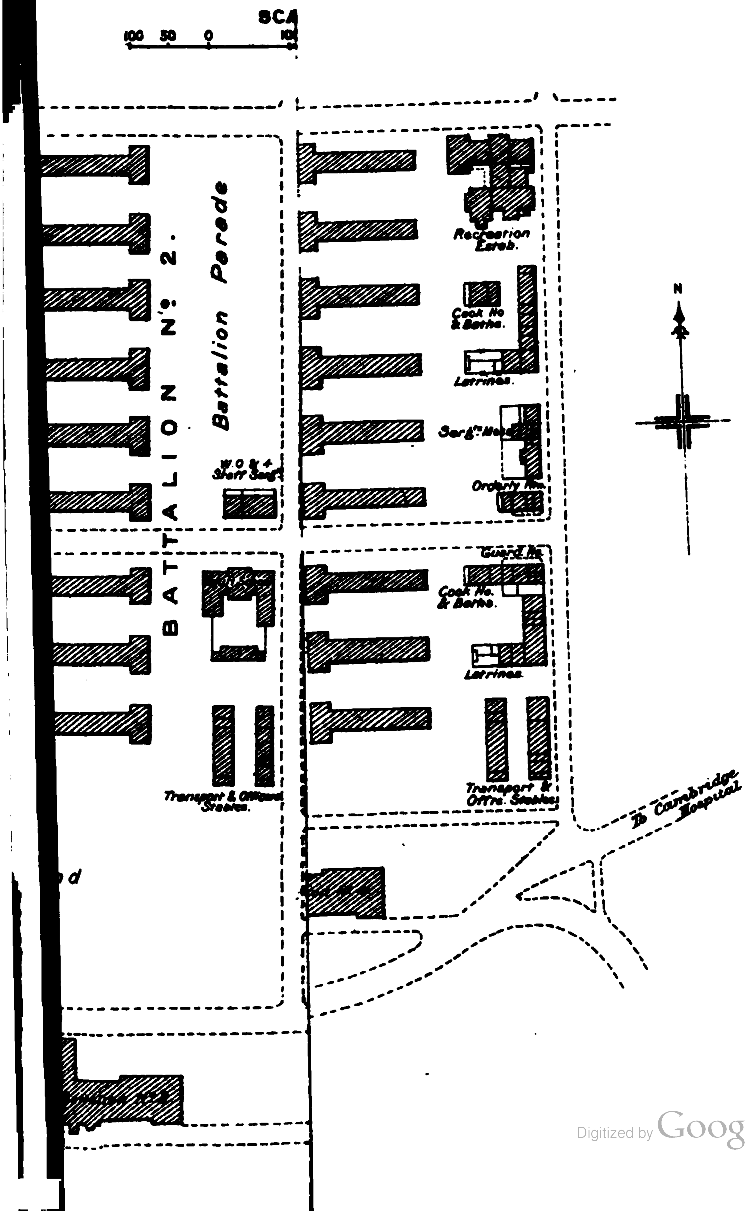

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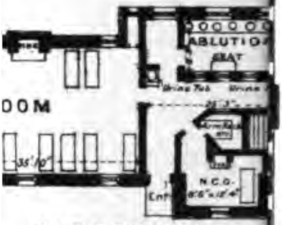

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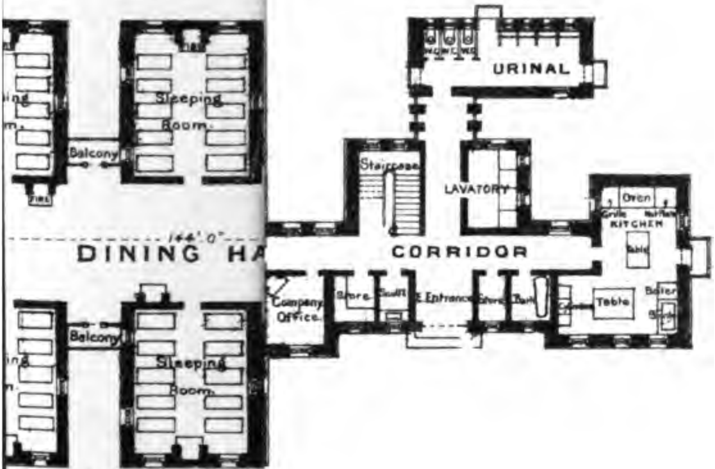

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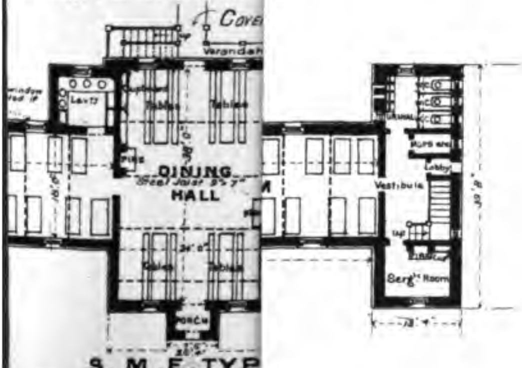

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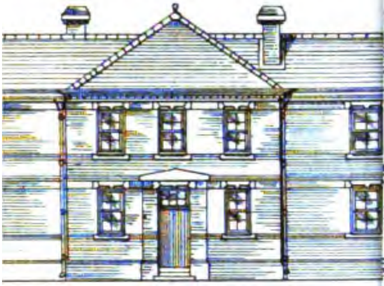

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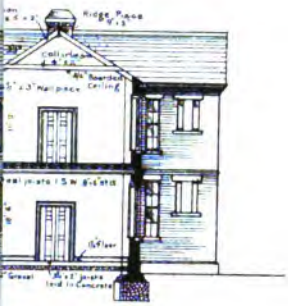

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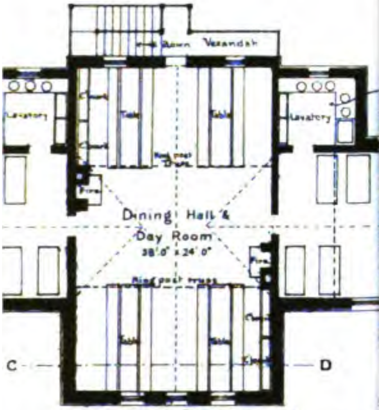

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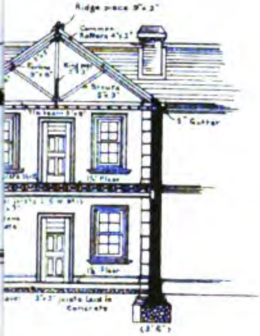

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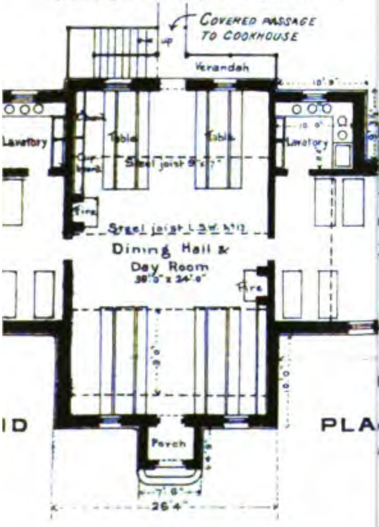

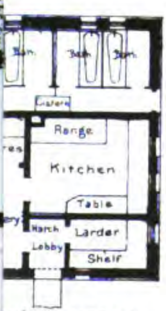

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PLATE IV.

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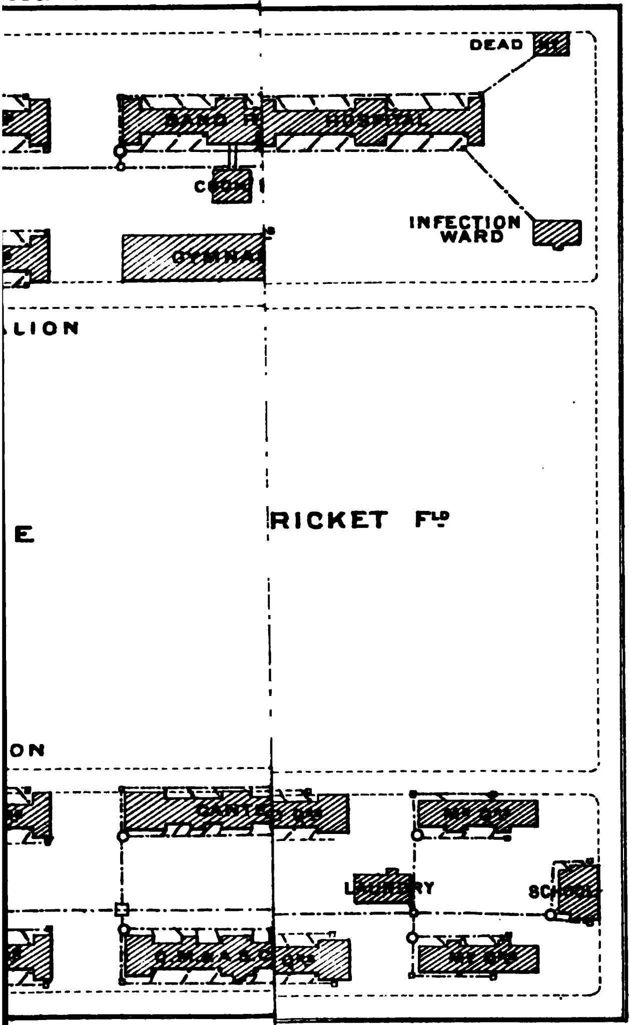

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SOLDIERS PLATE V.

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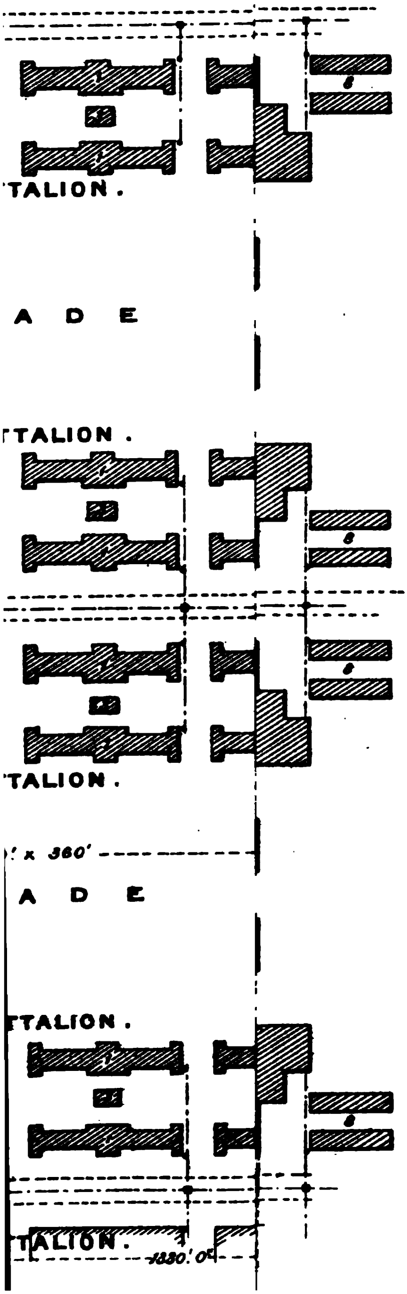

Reference.

1. Soldiers Qrs.
2. Reg^{tl} Institute.
3. Cook House.
4. Drill Hall.
5. Guard Rm. Orderly Rm. W.O's & Staff Serg^{ts} Quarters.
6. Q^{r} M^{rs} Stores & Q^{rs}
7. Off^{rs} Mess & Q^{rs}
8. Off^{rs} & Transport Stables.

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PLATE VI.

TYPE PLAN FO E.

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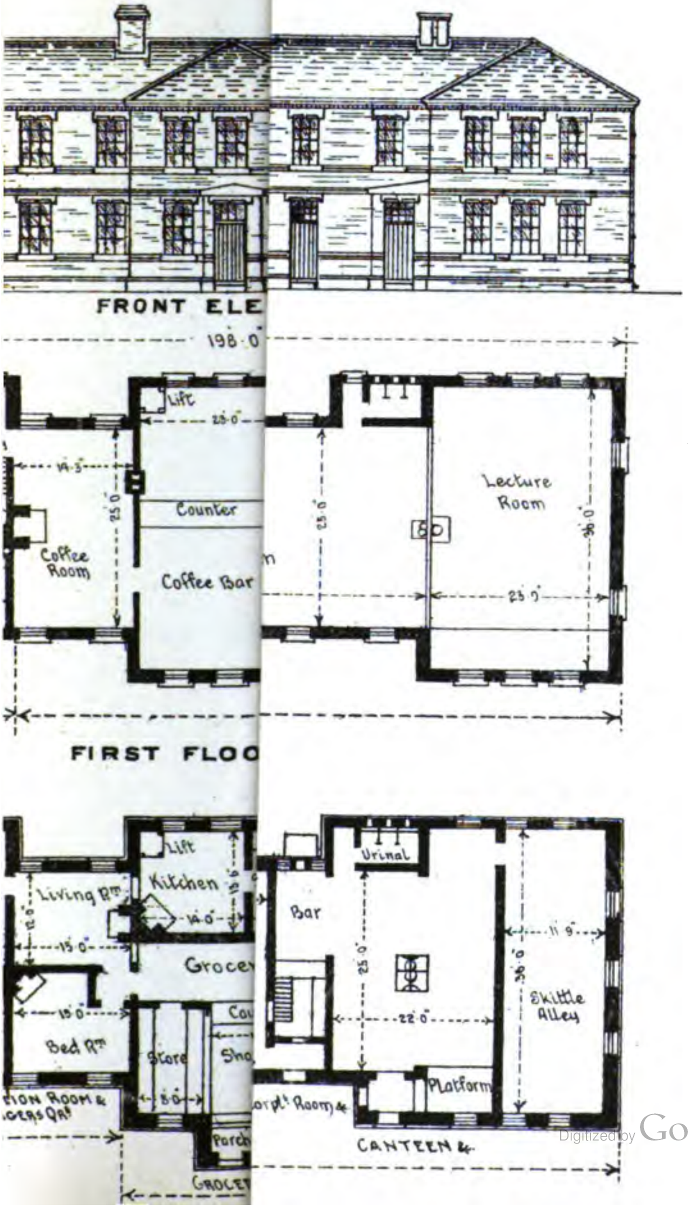

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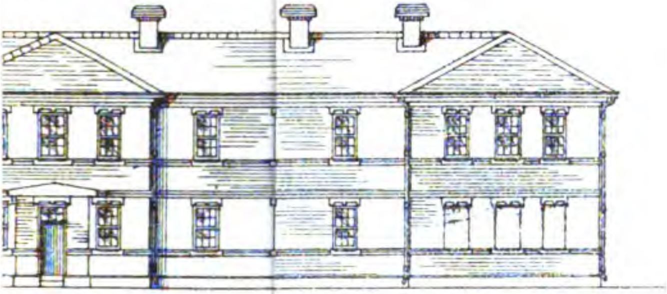

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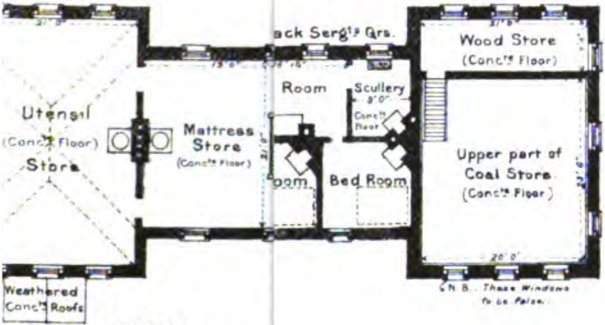

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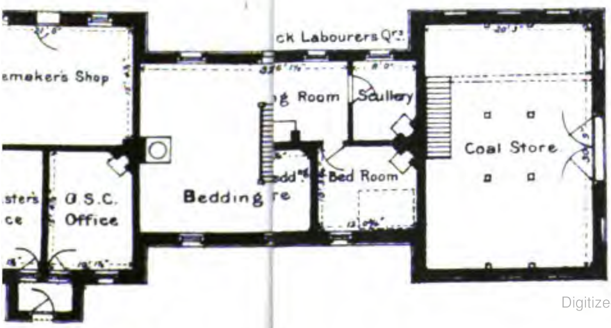

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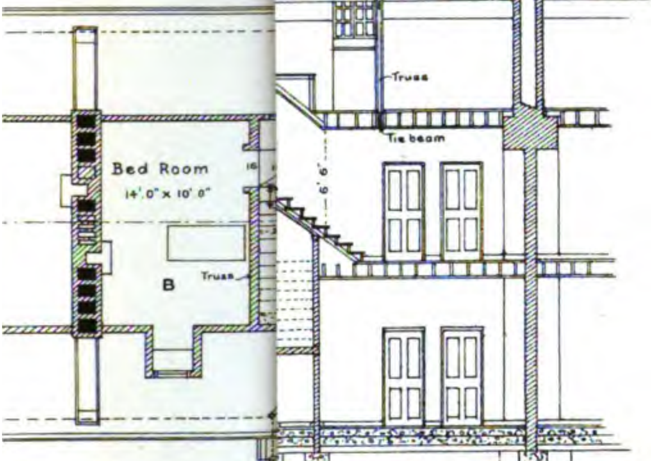

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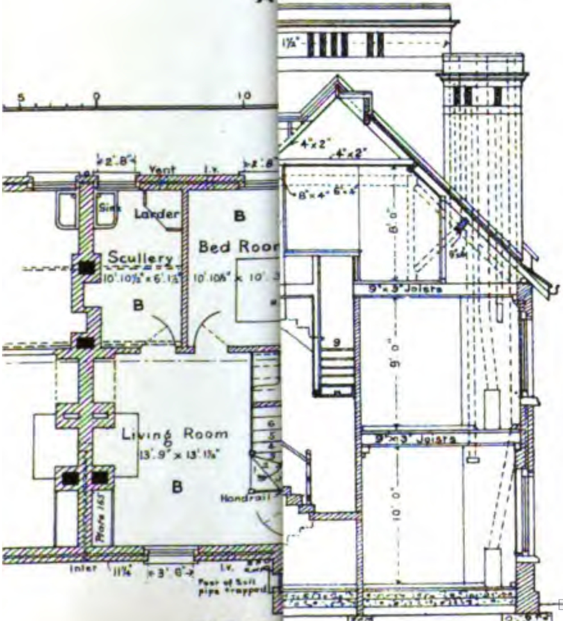

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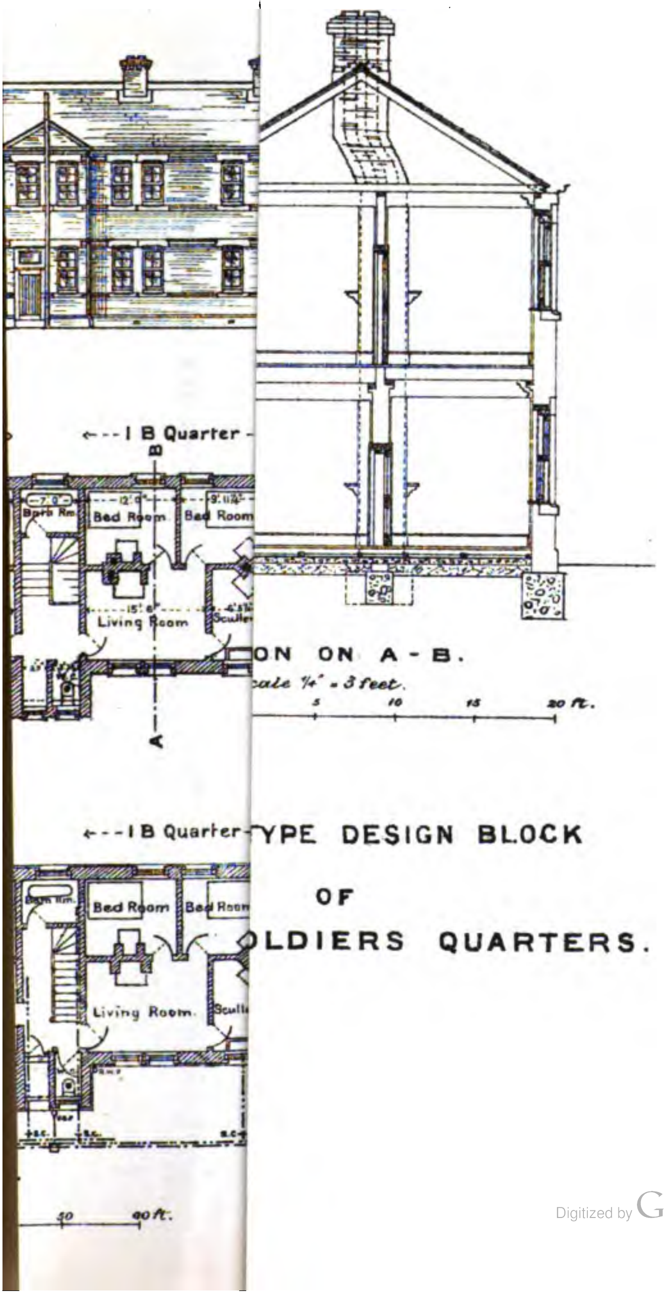

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TYPE DESIGN BLOCK

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PLATE X.

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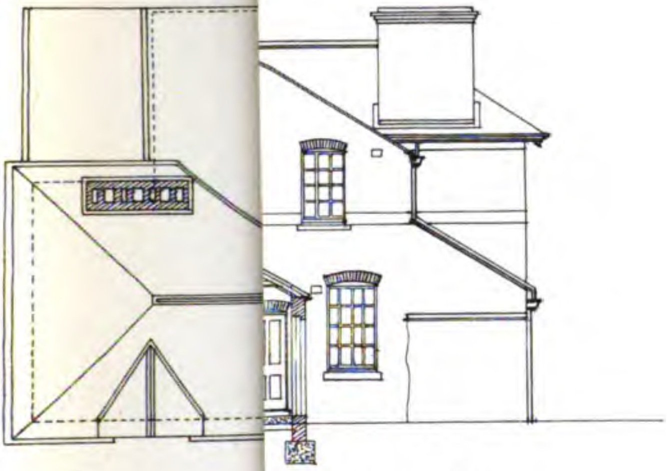

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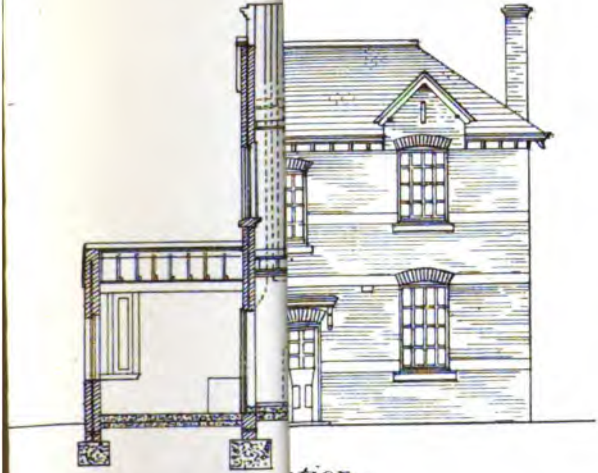

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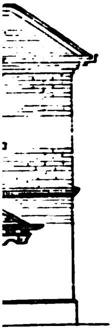

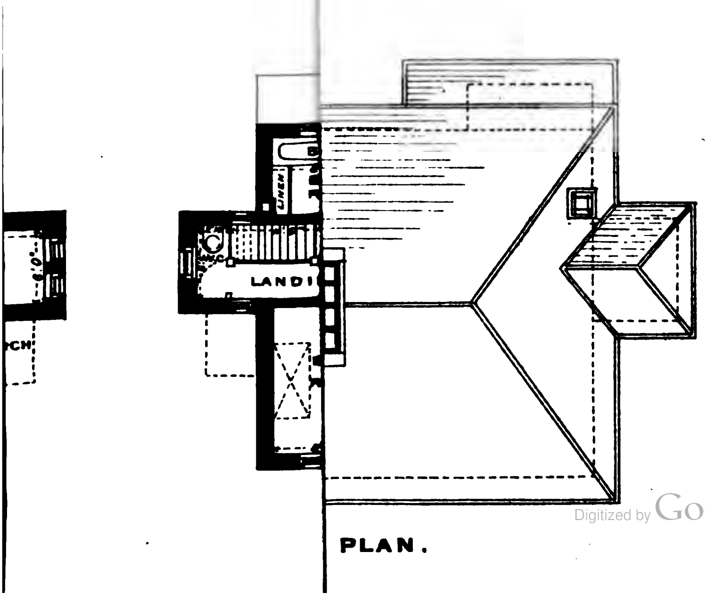

PLAN.

RAILWAY CONSTRUCTION.

PAPER VIII.

LECTURES ON
RAILWAY CONSTRUCTION

(Delivered at the S.M.E., Autumn Session, 1894)

By Sir Guilford Molesworth, K.C.I.E., M.I.C.E., M.I.M.E.

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PAPER VIII.

RAILWAY CONSTRUCTION.

BY SIR G. L. MOLESWORTH, K.C.I.E., M.I.C.E., M.I.M.E.

LECTURE I.

INTRODUCTION.

LUIGI COSSA, the eminent Italian economist, has given the following sound advice to students in political economy:—

"It is needful to hold ourselves aloof equally from the so-called doctrinaires, who refuse the assistance of practice, and from the empiricists, who obstinately close their eyes to the light of theory. The *pure* science explains phenomena and determines laws; the *applied* science gives guiding principles which practice brings into conformity with innumerable varieties of individual cases."

Again, John Stuart Mill wrote in one of his later works:—"One of the peculiarities of modern times, the separation of theory from practice, of the studies of the closet from the outward business of the world, has given a wrong bias to the ideas and feelings both of the student and the man of business. There is almost always room for a modest doubt as to our practical conclusions."

Similar caution cannot be too strongly impressed on students in engineering. It is an old saying that theory and practice do not agree, but this is a false assumption. Paradoxical results arise from the fact that the theory has been incomplete, and that, in its application, certain factors, which seriously affect the conclusion, have been omitted, and these factors can only be supplied by practice;

in fact, theory, to be perfect, must include practice and be bas upon it. It has been truly said "mathematics is a good servan but a bad master," and one of our eminent engineers h spoken of a mathematical education in college as simply providi the tools necessary for becoming an engineer. This is quite tru but the more perfect the tools, the better the work. The mo perfect your mathematical education, the better you will be able t solve the problems that practical engineering affords. On the othe hand, tools, however perfect, may be useless, or even dangerous, i unpractised hands; the sharper the tools the deeper they wil cut, and consequently the more mischievous they will be if wrongly directed. Too great reliance on crude theory, untempered by practice, may involve fatal mistakes which a practical man would instinctively avoid. For the performance of satisfactory work many accessories are required besides good tools, so, in order to become a successful engineer, something beyond a knowledge of mathematics is required. Engineering, though a scientific profession, means something beyond scientific knowledge. Let me illustrate this by a somewhat extreme case. You have often heard the expression "billiards is a very scientific game;" and so it is, but how many of those who play billiards understand the science of the game. Set a mathematician of the highest order against an ignorant but skilful billiard player, and what would be the result? The man who has never handled a cue may study the theory of billiards, and he will but dimly apprehend its application; but, on the other hand, if, after some experience, he should study the theory, he will see the aim of his study and direct his theory to the improvement of his playing; but, in addition to his science, he must have a good eye, a firm and skilful hand, judicious forethought, constant practice, and large experience. So the young engineer for one case in which he may require the use of high scientific attainments has to deal with innumerable cases requiring the exercise of common sense, gentlemanly and honourable feeling, tact, fertility of resource, energy, and experience, and these, combined with a sound scientific knowledge, are the elements which form the successful engineer.

Robert Stephenson used to say with great truth, "The most difficult, and at the same time the most important, branch of engineering is the engineering of *men;*" and there is little doubt that much of his success was due to his tact in the management of those under him.

Students on leaving college are frequently apt to be too well satisfied with their attainments to learn from those who have practical knowledge, and their knowledge is sufficient to lead them into difficulties from too great dependence on crude theory.

I speak from experience, for I remember well, in our students' visits to works, the self-complaisance with which we, in our imperfect knowledge, criticized the construction of works which we did not fully comprehend. When I left college I fancied that my knowledge of engineering was fairly complete, but I had not been many weeks in practical work before I began to realize the fact that there were a few things which I had to learn, and possibly to unlearn. As time went on these things increased and multiplied in the most marvellous manner, and now, at the end of a long professional career, extending over nearly half a century, I have reached that state of mind expressed by Professor Virchow, perhaps one of the most eminent of German scientists, "That which is my accomplishment as a man of science is precisely the knowledge of my ignorance, the chief thing is that I know what I do not know."

Now let me be distinctly understood that I by no means depreciate the immense value of high mathematical attainments; on the contrary, I think them of the very highest importance, and I would urge the necessity for improving that mathematical knowledge which you have already acquired; but *applied* mathematics are based on experience, and it must be borne in mind that practice is a factor necessary to make your theory perfect. Theory must go hand in hand with practice, and must be supplemented by it, but it too often happens that the engineer, after leaving college, neglects his mathematics, and, before he can reach that position in which his high mathematics would be really useful, his theoretical knowledge has become rusted by disuse. I cannot, therefore, too strongly impress upon you the need of not only keeping up the mathematical knowledge that you have acquired, but even improving it by the aid of practice, and I do urge the importance of a thorough combination of the practical with the theoretical whilst the engineer is young, for no after-experience can make up for the neglect of either. It is by climbing the ladder step by step that the practical engineer is made. It is the experience in all the minor difficulties of detail that makes the engineer, and such difficulties are apt to escape notice when met vicariously by the foreman, overseer, or contractor.

The officer placed at once in the higher grade immediately after leaving college can by no length of service gain that practical insight into work that is to be obtained by serving in the lower grades. Too often the officer is placed at first in charge of work the practical portion of which is performed either by the foreman, the contractor, or the clerk of works, and he naturally considers it beneath his dignity to learn from those over whom he is placed in command; and even if willing to learn, he does not come personally into contact with all the minor difficulties of construction, and the higher he rises in position the further he is removed from them.

Workshop training, when practicable, is a substitute for such "step-by-step" progress. It is of incalculable value to the engineer, even though he may not have to deal with machinery. The habits of precision, the knowledge and practice of good work, the acquaintance with details and materials, and the different modes of carrying out work in the best manner, together with the fertility of resource, gained by actual working at the bench, are invaluable to any engineer. But practical knowledge cannot be gained, as some suppose, by lounging about the workshop and watching the workmen, or by making models in the college workshop. It must be obtained in the school of life with definite aim and purpose, working as a workman amongst workmen, and doing work that has to pass the criticism of the foreman, and stand the test of actual working. In the engineering profession there are two classes equally valuable—that which executes work, and that which produces those formulæ which the more practical men employ. These two classes are composed of men entirely different, both in their qualifications and in their bent of mind, and it by no means follows that he who is eminent in one class must necessarily be so in the other. On the contrary, the most eminent would probably fail if called upon to carry out, unaided, a difficult task in the class which might not be his speciality. There are, of course, innumerable gradations between the extremes of such classes, in men who possess a happy combination of the theoretical and practical, but very great eminence in both are seldom combined in one and the same person. Men of high calibre are frequently wasted if placed by circumstances under conditions which do not call forth their special qualifications, and the exigencies of the public service frequently force officers into occupation, uncongenial with their particular qualifications, or unsuited to their past experience. Many cases have come to my notice of men of very high mathematical attainments who have signally failed in practical design. It has been urged by an engineer of some eminence that the man who cannot make a formula ought not to use it. I cannot quite endorse this sentiment, but I think that everyone who uses a formula should master the principles underlying it, or otherwise he may misapply it; and the indiscriminate use of, and blind reliance on, "pocket-book" formulæ, and the application of such formulæ to all cases and conditions, whether suitable or unsuitable, is an undoubted evil. Formulæ, as Dr. Anderson has pointed out, are frequently based on premises which are not accurately reproduced in practice, and which, in any case, are frequently unable to take into account collateral disturbances, which only observation and experience can foresee and common sense provide against.

I may fairly assume that all present have a thorough knowledge of the mathematical and theoretical principles of railway construction. I shall, therefore, make no attempt to touch upon such questions, nor will the circumscribed limits of these lectures enable me to enter into anything like a complete treatise on railways. I propose, therefore, to confine my remarks principally to practical questions that have come within the scope of my own experience, and to hints on those practical points which are not generally to be found in text-books or treatises on railways, and as your field of experience will probably be in railways to be constructed in new countries, or for military purposes, my remarks will refer chiefly to them.

First, let me say a few words on statistics. Statistics, like mathematics, are valuable tools, but they require very careful and skilful handling. There is nothing more dangerous than the indiscriminate use of statistics without a thorough knowledge of all the conditions that influence them. It has been said, "You can prove anything you like with statistics," and certainly I have known the same statistics used to prove diametrically opposite results. For instance:—A railway with light trains, small traffic and empty returns, judged by the statistics of "train-mileage," might appear to be working more economically than another railway on which the trains were heavy and well filled, whilst the statistics of "ton-mileage" would indicate exactly the opposite result. No two railways are exactly alike in the almost innumerable conditions on which such statistics depend. The East Indian Railway, for example, works under the conditions probably more favourable to economy than any other railway in the world. The gradients are light, the traffic exceptionally favourable to full loads in both directions at all times of the year, it has its own collieries, its fuel is cheap, its gross earnings enormous, and comparisons that have been made between its statistics and those of a State railway of smaller gauge have been taken to indicate the great inferiority either of State management or of the smaller gauge. On the other hand, if we take similar statistics of the Madras Railway, on which the conditions prevailing on the East Indian Railway are entirely reversed, they will appear to indicate a superiority either in the State management or in the smaller gauge. Manifestly, inferences drawn from such comparisons, without duly weighing all the conditions, are not only utterly useless, but absolutely misleading, yet I have been over and over again confronted with such comparisons.

GENERAL QUESTIONS OF ECONOMY.

Economy in construction is of such vital importance that every effort should be made to study economy and check extravagance. There are numerous causes tending towards economy, and the progress towards extravagance is so insidious, that it is almost impossible to check it, unless all concerned are imbued with the spirit of economy.

Provision beforehand for every possible contingency is a very common source of extravagance, and one of the most difficult of control. Naturally, it is considered a reflection on an engineer to make an estimate and afterwards to find that a large number of things are necessary for which no provision has been made; but, if provision be made in the estimate, the works are sanctioned, and the money will be spent. This is specially the case with water-ways and station accommodation. In India, it is almost impossible to foresee how the drainage may be affected by the construction of the railway, and it is necessary to make very ample provision for water-way. Frequently it happens that, after a large water-way has been given, the floods attack the line in some unforeseen way, or in some unexpected place, and considerable additions are needed. When this happens the engineer is apt to go off to the other extreme, and provide more than ample water-way, so as to avoid the reproach of having under-estimated the flood. Possibly, moreover, the flood may attack one part of a railway one year, and a few years afterwards entirely change its tactics, leaving the portion previously attacked quite free, and bearing heavily on another part that has escaped in former years. This is especially the case with those rivers which pass through alluvial districts, and possibly run on the highest part of the plain. Again, there are in some districts floods of an exceptional character which may not occur once in 20 or 30 years, and possibly may never occur again. In such cases it may sometimes be possible to supplement a bridge by an arrangement in which the surplus water of an excessive flood may pass without injury over a low portion of the line specially protected.

Although it is the duty of the engineer to foresee such contingencies, it may not always be advisable to execute them in the earlier days of construction. In most railways on the plains of India, where the line is formed on low embankments, it is better to provide, where practicable, the minimum of water-way absolutely necessary, and to construct low protected causeways in the approaches in such a manner as to prevent danger to the bridges The abutments of bridges also in doubtful places should, if practicable, be "pier abutments," which will allow of expansion without demolition of the existing work. The provision for every possible contingency in station accommodation, staff quarters, etc., is a prolific source of extravagance. A line should be first opened with the minimum possible amount of station accommodation, and in some cases with temporary buildings and expedients. It frequently happens that provision is made for traffic that may never come, whilst traffic is abundant at stations for which no provision has been made; but in all such arrangements the buildings should be so designed and placed as to allow every facility for expansion should it be found necessary. I am far from advocating an absence of foresight for contingencies, but I believe it would be better to prepare for sanction an estimate only for the work and stock, etc., absolutely required for the given amount of traffic. This should be supplemented by another estimate indicating the work that may possibly be necessary under certain conditions, so that the total cost which may possibly be expected on the project may be known beforehand. Another prolific source of extravagance is found in the little but manifold wants of the manager after the line has been opened for traffic. The manager, as a rule, has no interest in keeping down the capital expenditure. He does not provide funds for it, and as he had nothing to do with the framing of the original estimate, no responsibility is attached to him for any excess beyond it. The traffic manager or locomotive superintendent, seeing that efficiency of working may probably be increased by certain additions, or that certain expenditure may afford great convenience, applies for additions, which may be termed "luxuries of management," and which it is very difficult to say are not necessary. In order to check this tendency it is desirable to insist, as far as practicable, on the question being reduced to such a form as to show a money value for the addition. It should be shown that there will be a direct economy in working by the proposed addition, and that the money value of that economy will justify the expenditure: if not, the outlay should be resisted; "luxuries of management should be strictly forbidden." Of course, it will happen that many exceptional cases will often arise to which this rule cannot be applied: when it is impossible to reduce the question to a money value, or when it is simply a matter of convenience or safety of passengers, and in such cases it is necessary to exercise a prudent and comprehensive discretion, keeping in view, as far as practicable, the principles of true economy.

Another prolific cause of extravagance is found in the traditional excellence of the character of all structures connected with railways, and the desire that exists to turn out a creditable job; on some small narrow-gauge branch lines there is a tendency to have everything as perfect and complete as on a large broad-gauge trunk line. The engineer does not like the symmetry of the station to be marred by temporary or shabby structures, and I have frequently met with handsome brick structures, panelled doors, cut stone floors and verandahs, and similar luxuries for the native station-master, who has been accustomed all his life to mud walls and floors, and to doors and windows, if any, of the roughest description. The plea that it does not add much to the total cost of the railway is not to the point. Large totals are made up of insignificant details, and the neglect of the study of economy in every detail causes extravagance. It is the right policy to make the employees of the railway contented with comfortable staff quarters, but in many cases this result may be accomplished with buildings of a less expensive character than many I have seen.

But whilst urging economy generally, I am opposed to the false policy of unduly sacrificing economy in maintenance, or efficiency in working, to cheapness of first construction. I am opposed to the adoption of light rails, if the saving so gained either leads to the rapid wear of the rails and rolling stock, or necessitates a reduction of the train loads below the economic limit. It is false economy to allow inferior work, especially when the safety or stability of structures is at stake. Whilst on this subject I wish to point out that good work in masonry does not necessarily imply expensive work; in fact, bad work may be more expensive than good in first cost. An instance of this occurred to me in one of my inspections, when I found rubble masonry of a kind that I could not approve, and the officer in charge pleaded that the stone was so refractory in character that he could not afford a better class of masonry at the rates of the estimate. I replied that I could not allow such a plea for inferior work, and that if he could satisfy me that it could not be done within the estimate, the rates should be raised, but I doubted the necessity. A few months afterwards, when visiting the same works, I found that the masonry was of a most excellent character, and the officer admitted to me that the cost was rather less than that of the inferior work which I had condemned; the extra trouble and labour were more than counterbalanced by the saving in mortar.

In masonry, good work requires care and organization, rather than extra expense. All that is necessary is a little trouble to be taken at the outset—in the quarry, by careful organization in gauging the stones to one standard of thickness; stacking stones of each class separately; using one thickness only at a time in any work; carefully examining each stone to ascertain the class to which it may be converted with the least amount of labour; and making the foreman and workmen in the quarry fall into regular systematic habits—a few hours now and then spent by the engineer in the quarry organizing a system and explaining the best mode of working up the stones will soon produce the desired effect. In cases where refractory stone is used, masonry may be divided into classes, according to the work it has to perform, whether in high, thin piers, or work exposed to much vibration, or in larger masses exposed to less vibration, or in work not exposed to any severe conditions; and an inspection of any stone will determine the class to which it should belong; if it should be of such a shape as to require much dressing to fit it for the superior class of work, it may be used in the inferior class. Judgment in *getting out* the stone is often productive of economy; it frequently happens that by placing the shots judiciously the stone may come away in such form as to require but little dressing. The use of wedges, also, instead of blasting, with some kinds of stone, though perhaps slower than powder, and apparently less economical, is sometimes productive of economical results in lessening the amount of dressing necessary.

Another cause of extravagance is a too rigid adherence to type drawings or standards under all circumstances. Types are intended for general information, and to secure, as far as practicable, uniformity; but it is obvious that they cannot be adopted inflexibly in all cases under varying conditions of districts, materials, workmen, climate. I have found an engine shed in such a position that its cost was considerably increased on the depth of foundations, simply because it was shown in that position by the type lithograph, whereas by moving it to an equally convenient position half the cost of foundations might have been saved. In other cases I found platform walls and embankments carried down to depths of over 10 feet for foundations where some cheaper expedient would have answered equally well. In some of the minor branch lines temporary water arrangements, signals, tanks, etc., might be adopted with advantage at first, and tanks supported on sleeper stacks below the standard height might be allowed; distant signals might also be dispensed with at unimportant stations. In fact, it must always be borne in mind that small feeder branch lines do not require the perfection and completeness that is expected in main lines of greater importance and large traffic.

Types and standards, like formulæ, if used without discretion, are worse than useless; but, taking them as a whole, I have found type drawings of great value, although it is necessary to guard against their misuse.

Another source of extravagance, perhaps the more dangerous because not so directly observable, is the habit which some officers have of treating contractors with improper severity. In a contract it is necessary to insert a number of penal clauses that are only intended to be put in force in case the contractor should attempt to carry out his contract unfairly; such clauses give the engineer immense power, and if he choose to exercise it unjustly, he is able seriously to injure the contractor, although keeping within the strict letter of the contract. The more important of these clauses should never be put in force without absolute necessity, and even then with great caution and circumspection by the engineer-in-chief himself, who should not delegate his powers to his subordinate officers except under urgent necessity. Yet I have sometimes found executive, and even assistant, engineers freely and injudiciously exercising these powers.

In the administration of a contract, the first duty of the engineer is to his employer, the second to the contractor, and the engineer is bound, not only in simple justice, but also in the interests of his employer, to assist the contractor in every way, so long as he does not thereby prejudice the interests of his employers. As a rule, the contractor ought to be allowed any advantage that would be admitted if the work were carried out departmentally. The engineer, being vested with enormous powers, may, and sometimes does, misuse them in raising frivolous objections and putting the contractor to needless expense, or in placing unnecessary difficulties in his way. When he does this, it may re-act on his employers in two ways: either the contractor may break down his contract, which is generally almost as serious to the employer as the contractor, or it may give the employer a bad name, and cause contractors in future contracts to increase their rates to compensate for the unnecessary expenses into which they may be forced by the engineer. Several instances have come to my knowledge in which contractors have added to their rates in tendering for a contract that would probably be administered by an unjust or injudicious officer. It must, moreover, be borne in mind that an inequitable agreement, however strongly worded, is frequently ruled in law courts to be null and void, and penal clauses, if unjustly administered, will not stand. In a case that came before me this year for my arbitration, I was obliged to give my award on one point in direct opposition to the terms of the contract, which, though distinct in their meaning, were inequitably enforced. On the other hand, I would not be understood to countenance any laxity in the supervision necessary to secure either good work or to safeguard the interests of your employers. It is especially necessary to prevent an unscrupulous contractor from "skimming the cream" of a contract by executing all the easy and remunerative work and then relinquishing the contract, leaving the heavy and non-paying work to be done by others. Careful provision should be made in every contract to prevent such a contingency.

RECONNAISSANCE AND SURVEY.

The reconnaissance of a railway should only be undertaken by an officer of special training and great experience, one who has what may be termed "an eye for the country." His experience should not be merely that of a surveyor, but also of a constructor of railways, for errors in reconnaissance are often of a very serious character. There is a great danger of drawing hasty conclusions. In one case, after the reconnaissance of a mountain range, I arrived at the conclusion that a line could be made through a particular mountain pass with a gradient of 1 in 40, and a tunnel of about 3 miles in length, and I recommended a preliminary survey to ascertain the practicability of this suggestion. Unfortunately, the officer to whom the survey was entrusted formed an opinion, from mere inspection of the very difficult features of the pass, but without any instrumental examination, that the plan was impracticable, and he wasted two years, with a very large staff, on a *detailed* survey of two passes, in which a preliminary survey of the difficult portion might have shown at once to be impracticable. Subsequently the survey was transferred to another engineer, who proved in a very short time by preliminary survey that a fairly easy line, almost as originally suggested, could be obtained with a gradient of 1 in 40 and a tunnel of about 2½ miles in length, and the line was ultimately constructed on that basis.

It is impossible to lay down any fixed rule for reconnaissance, which must vary with the features of the country. The most difficult cases are those in which densely-wooded forests and jungle is met with; especially when the general direction is not fixed by any obligatory points, such as the crossing of some large river, or the necessity of accommodating some town or military station. Sometimes I found it necessary to have four camps out at once, passing down the centre of the district and riding out 15 and 20 miles on either side to examine every alternative. An experienced eye will almost instinctively grasp the character of the country, but to reconnoitre successfully, the engineer must accustom himself to judge of the relative heights and distances, which are sometimes very deceptive in appearance, misleading inexperienced eyes. Looking up a declivity, for instance, the rise appears to be less than it actually is; whilst looking down, the fall appears to be greater. It is, therefore, always desirable to examine such localities from both points of view. In a rolling country, when standing on the summit of one undulation, the depth of cutting or height of embankment required for the railway invariably appears to be greater than it will eventually be in reality. A plain with a considerable rise towards mountains, when looked at with a backing of mountains, will sometimes appear to be falling towards the hills when in reality it is rising. and a view from elevated ground is very apt to dwarf the difficulties that have to be met on ground of a lower level. Again, the inexperienced eye is apt to exaggerate the difficulties of sharp angles, steep slopes, and rugged rocks.

If maps of a country exist, much is to be learned from a study of them; and the power of interpreting a map correctly is of infinite value to the engineer. It is often possible to deduce very valuable information from a careful study of the rivers, their flow, their position with regard to each other, their ramifications and sinuosities.

I may instance the case of the proposed railway from Mombasa to Lake Victoria Nyanza, about 600 miles in length, through a difficult and almost unknown part of Africa, rising from the coast to a summit level of 8,500 feet above sea level. Although the maps of the country were of the most meagre description, yet a careful study of them enabled me to determine the general direction of a route, the subsequent survey of which completely confirmed the deductions I had drawn from the study of those maps. In fact, the route adopted as the result of the survey was stated, in the report presented to Parliament, to be practically that which I had proposed as the only probable chance of obtaining an inexpensive railway; the main point of difference being the descent into the Lake Victoria Nyanza, by which the length of the line was considerably increased, but the gradients improved. It may, perhaps, be useful to mention some of the more prominent deductions that may be made by a study of maps. First, sinuosities of a tolerably regular character, combined with a fairly straight direction of the general direction of the river, as shown at **AA**, *Fig.* 1, *Plate* I., indicate the existence of a valley flat in cross section, with no great fall. Second, streams tolerably straight and fairly parallel, without any feeders or ramifications, as shown at **BB**, *Fig.* 2, *Plate* I., denote a flat country, and if these streams overlap the tributaries of another river, it may be assumed that the watershed is flat, and there is no high ground separating the different drainage areas. Short feeders with ramifications, as at **CC**, *Fig.* 2, *Plate* I., denote a more rapid ascent and broken ground. The magnitude of this ascent may, to some extent, be gathered from a study of their relation to the streams of the adjoining drainage area. Third, irregular bends with numerous ramifications, especially if they double on themselves, as at **DD**, *Fig.* 3, *Plate* I., or are marked with small lakes, indicate a mountainous country and broken ground. Fourth, the lowest portion of a district is denoted by the confluence of rivers towards that part, as shown at **E**, *Fig.* 4, *Plate* I. Fifth, the highest portion, **F** (*Fig.* 5, *Plate* I.), is denoted by the divergence of streams from that point. If the ramifications cease to be marked, and the space between the ramifications is blank or only marked by one stream, this indicates the existence of a plateau or basin. Sixth, the divergence of two streams originating at a point **G** (*Fig.* 6, *Plate* I.) indicates the existence of a ridge, in which there is a depression at **G**. Seventh, when two streams run parallel to each other and then diverge, it is probable the point of divergence **H** (*Figs.* 7 and 8*a*, *Plate* I.) is a low point in the ridge between them. Eighth, when a river divides in its downward course into several channels, it is an indication of a change to a flatter slope at the point of division **K** (*Fig.* 8, *Plate* I.), if it is inland, and an indication of a deltaic formation if it is near the coast. A sudden increase in the width of the river frequently indicates that a more level tract has been reached. Ninth, streams denoted in the diagram by the letters **LL** (*Fig.* 9, *Plate* I.) indicate that they take their rise in the somewhat abrupt and broken ground, and fall into comparatively easy slope as they approach the main river. Their parallelism indicates that the spurs or undulations between the streams are probably parallel and in the same direction as the streams themselves. Simultaneous ramifications, nearly at right angles to their course, indicate depressions in the ridge, or undulation, between them.

On the right hand the shortness of the feeders at **M** (*Fig.* 9, *Plate* I.) denotes probably a sudden rise; the absence of feeders at **N**, rocks or escarpment; and the ramifications at **P** broken ground.

The cross section of the drainage area of *Fig.* 9 would probably be somewhat as indicated at 9*a*.

To the eye inexperienced in reconnaissance, the left bank would probably afford the best promise of an inexpensive line, but the cost of rounding or cutting through the spurs, the expense of crossing the numerous water-ways, and possibly the greater liability to slips, *might* possibly render it the more expensive line of the two.

The difficulties of rocks and escarpments, sometimes so formidable at first sight, frequently yield to a successful study of the means of grappling with them. The photographs of the "Sensation" rock (*Plate* II.), the Mean-Galla gallery (*Plate* III.), and the "Perforated" rock (*Plate* IV.), on the Ceylon Railway incline, show how some of these difficulties have been surmounted in practice; and in this case the ascent of the mountain zone was accomplished at about £400,000 less than the estimated cost of another ascent far more tempting at first sight, and of a character corresponding more nearly to that assumed in the left hand of the diagram (*Fig.* 9, *Plate* I.).

For reconnaissance, I have found a small instrument, of French design and make, an extremely handy instrument. It consists of a combination of magnetic compass and clinometer in two separate rings mounted on the same axis, the rings being graduated on their edges, and a fine platinum wire, passing close to these edges, without touching them, enables the graduation to be read with ease and accuracy by means of a small magnifying glass, which closes a small aperture in front of that portion of the graduation which is visible. The instrument may be held in the hand, but it is so arranged that it may be readily socketed with an universal joint on the top of a pointed rod, which may be stuck in the ground for steadiness of observation.

The most simple mode of reconnaissance in mountainous country is with aneroid barometer and compass, perhaps supplemented in difficult parts by rough plane-tabling. Barometer readings cannot, however, be relied upon for *absolute* heights, though they may be used with advantage to determine *relative* heights in reconnaissance; but even then great caution is required, for there is a degree of uncertainty about them in consequence of local atmospheric depressions and the diurnal wave, which are sometimes embarrassing. If possible, check observations should be taken at some fixed stations by an independent observer, say every half-hour throughout the day on which a reconnaissance is made, but even these are subject to error from local variation, especially in stormy weather.

In England the diurnal wave (shown in *Plate* V.) is of little consequence, being insignificant in extent, but in the tropics it may vary to an extent equivalent to a difference of level of 80 or 90 feet in the course of a few hours. Yet I have found engineers, engaged in barometrical observations, utterly ignorant of the existence of the diurnal wave, and consequently making no allowance for it. The diurnal wave is, as a rule, at its maximum about 10 or 11 o'clock, and its minimum about 4. The wave, however, varies according to season, weather, and elevation. It has always been my practice to construct a typical barometric wave from observations made when halting, and to take every opportunity of checking this typical wave, from which I constructed a table of corrections varying according to the hour of observation; and though there must, of course, be some uncertainty in such correction, yet on the whole I have found my typical wave fairly reliable and very useful.

In my reconnaissances in the enemy's country, when it was inconvenient, not to say dangerous, to dismount, I found it useful to have a field-book ready ruled in columns for date, time, barometer reading, temperature, etc., in a special open-faced pocket on the outside of the left sleeve, and also to have my aneroid carried in a belt similar to a railway guard's shoulder watch-belt, allowing the open face of the aneroid to show, thus enabling me to make and record the observations without interference with my bridle hand, and to avoid all danger on a fidgetty horse of dropping the aneroid. In this manner I have been able rapidly to record my observations without stopping my horse, whereas before I made this arrangement I had invariably to stop and dismount, and each observation required a considerable time. The belt had an arrangement by which it could be rapidly shortened up, so as to house the aneroid close under the armpit, in order to avoid its jolting about when galloping; and the pocket on the sleeve was protected from the rain by a waterproof flap, which could be buttoned back in fine weather or when observations were required to be recorded. The hypsometer, or boiling-point thermometer, though inconvenient for ordinary observations, is a very useful accompaniment to the aneroid for occasionally checking it, as the aneroid is a delicate instrument liable to get out of order, and the hypsometer is portable, very reliable, and not so liable to injury as the mountain barometer. It should not, however, be used with dirty or greasy water.

Aneroids should not be taken to a greater altitude than that for which they have been graduated. I have known an instance in which expensive aneroids were indented for, but they were only graduated for 4,000 feet elevation, and naturally when sent up to 7,000 feet the vacuum boxes were injured under the decreased external pressure. Care should, therefore, always be taken, in ordering aneroids, to specify that they should be graduated to an extent equivalent to the maximum elevation to which they are likely to be taken. In some cases of reconnaissance a pocket pedometer may be useful. It may be used on foot or on horseback, of course correcting the observations by measurement of the comparative length of the paces of a horse or man. Time occupied in marching may also give an idea of the distance travelled. In one case I took a rough section of a mountain pass, on a camel, by halting and sending forward on another camel an assistant, who counted the number of paces made by his camel. At intervals I called upon him to halt, and taking an observation to him by compass and clinometer, I then took his place and sent him on again. The length of the camel's paces was ascertained by measurement of the length which the camel covered in a certain number of strides. The approximate section, thus made in an extremely short space of time, subsequently proved by instrumental examination to be a very fair approximation, at all events sufficiently so for the purpose for which it was required, which was to decide whether the route through that pass was practicable.

Forest and jungle present the greatest obstacles to either reconnaissance or location of a railway. When it is impossible to obtain a view around, it may be necessary that reconnaissance should take a form of a trial survey more or less complete. In such cases a trial line by compass may cut through the forest, leaving level pegs at intervals, from which cross sections can be extended on either side as may be found necessary.

Exceptionally thick patches of bamboos, cane thickets or thorn, which form a dense and impenetrable mass, may be temporarily avoided by taking a parallel line round them, leaving the actual trial line to be completed at leisure. In some cases where jungle paths or roads follow nearly the required direction, it may save time to use them as a base of operation by running a preliminary traverse upon them.

Generally speaking, a preliminary survey is required, in much greater detail than a simple reconnaissance, before the line can be permanently staked out. The general plan of operations in fairly easy and open country, is to run a theodolite line as nearly as possible on the intended line, leaving the curves unstaked, but making the intersection points of the straight lines serve as a preliminary base for the survey, which may at first be filled in by plane-tabling or ordinary survey, as the case may require. If this line be laid out with intelligence, it may serve permanently as a staked-out line, but whether this be the case or not, it is very desirable to leave on the ground permanent records of the work done, so that any future survey party may take up the work at the point where it has been left, and not to have to start afresh. It is impossible to exaggerate the loss of time sustained in taking up a survey on ground previously surveyed if no definite record can be found on the ground; and it not unfrequently happens that old field-books are useless from want of a proper system in keeping an index of their contents, headings of their pages, proper description of the bench marks, and definite information respecting the chainage, if the survey has been started simultaneously from several points.

It frequently happens that construction, or even staking out, are not commenced for a considerable time after the preliminary survey has been made, and unless a proper system of records be observed the results of the preliminary survey may, to a great extent, be lost, for it frequently occurs that an entirely different staff may have to take up the work.

In a trial line, ascending or descending a valley in a mountain range, when the sides of the valley are not much broken and fairly straight, I have sometimes found it convenient to assume levels representing the average fall of the railway at certain points, and after fixing these points by flying levels, to pick them up by means of a traverse, from which cross sections on either side can be taken on side-long ground. For such cross sections I have found a clinometer quite sufficient, and the cross sections are much more expeditiously made than if taken by theodolite or level. In a broken country I have sometimes found it necessary to fix a ruling gradient and then run a preliminary traverse line, following as closely as possible the contour at that gradient. In such cases, however, it should be remembered that the line as set out is generally shorter than the traverse line, which consequently should be run at a slightly steeper gradient than that which is to be ultimately adopted. This traverse line should be closely followed by levels and cross sections so as to be able to make correction should the traverse be found to be falling either too rapidly or insufficiently.

In a long continuous incline it is convenient to introduce at intervals of three or four miles a short piece of level about the length of an ordinary train. It eases the train in ascending and enables the driver to check it in descending. It also may frequently enable a saving of work to be effected by judiciously arranging the level in such a position as to pass above or below some difficult point.

When the line has been staked out, it is desirable to arrange permanent marks in such a manner that they may not be lost or destroyed during the execution of the works. Bench piles, for example, should be placed on one side of the railway at the commencement of every important cutting and embankment, and near every large bridge, in such a position that they are not likely to be disturbed when proceeding with construction, and a note of such bench marks should appear on the plan, giving the direction and distance from any given chainage peg. The tangent points of curves should, in like manner, be capable of being found by cross lines from pegs set out clear of the work at an angle of 45° to the tangent. The intersection and tangent pegs and all other important pegs should be protected by rough masonry built around them.

In a very long continuous incline on side-long ground, money may be well spent, before commencing construction, in making a bridle road as nearly as practicable on the contour line of the gradient. This road will pass the mouth of every cutting at formation level.

Borings and trial pits should be made before commencing construction in order to ascertain the character of the cuttings and the depth of foundation of the ridges. A common 1½-inch or 2-inch pod augur, with rods, will enable borings for cuttings in soft material or for shallow foundations to be made in a few minutes, if the material be not too hard. Tube wells may also be used with advantage to indicate the depth of a firm stratum and below the surface; they are also useful in ascertaining whether water is to be found within depths of 26 or 28 feet. In sandy or gravelly soil, if the ground be not too hard, the tube wells may be driven with depths of 25 to 30 feet in the course of from three-quarters of an hour to an hour and a-half, according to the hardness of the ground, but, of course, they cannot be driven through rock. For sandy rivers in which a substratum of boulders or other hard material is believed to exist, boring to ascertain the depth of stratum may be made by means of a gas-pipe, about 1-inch diameter, which can be rapidly sunk by means of a small hand-pump, water being forced down the pipe to clear away the sand below the pipe, which is pushed into the cavity thus formed. When deep borings are required, regular sets of boring tools are required, and a few hints may be useful. If pipes should stick they may probably be started by turning them, as indicated in *Fig.* **A**, *Plate* VI. The shear-legs should be as high as possible; the ordinary three-legged derrick is awkward and too low. Diagram at **A**, *Plate* VI., gives a sketch of a useful form of scaffolding. To hoist the pipe, use the winch directly over the pipes, as in diagram at **B**, *Plate* VI.; sometimes a long pole, as indicated at **C**, *Plate* VI., may be usefully employed in extracting the pipe. Never use rods with a tool that does not require them; a small wire rope is much more rapid in action. Borings can be taken from a platform built on two boats, as shown at **D**, *Plate* VI., provided there is not a swift current or large waves; but should these conditions not be fulfilled, a movement of the boats will probably break the pipes about the ground line. In such cases a pile staging will be necessary, which would probably be beyond the resources and out of the province of the survey officer.

GAUGE.

The subject of the gauge to be adopted is one which I wish to bring prominently to your notice, because it has given rise to more discussion, greater misapprehension, and a larger waste of money than any other question connected with railways. The battle of gauges arose at a very early stage of railway history, when Brunel adopted the gauge of 7 feet for the Great Western Railway, instead of the standard gauge of 4 feet 8½ inches, which had been adopted by Stephenson as the average of tramways on which ordinary carts ran.

The 7-foot gauge did not, however, appear to commend itself, though possessed of some advantages as well as disadvantages, and it did not extend beyond the tributaries of the Great Western Railway; but the disadvantages of break of gauge were found to be so great that in 1892 the 7-foot gauge became extinct. About 24 years ago, a series of articles in the *Times* stirred up afresh the battle of the gauges in the other extreme. These articles endeavoured to prove that the Festiniog Railway, of the exceptionally narrow gauge of 2 feet, enjoyed a prosperity which contrasted most favourably with that of the broader gauge railways of Great Britain. The dividends of the Festiniog Railway were shown to be 29½ per cent. on the original capital, the percentage of expenditure to receipts, 43½, compared with 48 of the average English railways. The dead load was also shown to be very small, compared with that of the rolling stock of the broader gauge, and the cost of construction was low.

These articles had the effect of misleading those who were not practically conversant with railway management, and gave to the public an exaggerated idea of the advantages of an exceptionally narrow gauge. Several of the Colonial Governments having in consequence expressed a desire to adopt the exceptionally narrow gauge, I was deputed by the Secretary of State for the Colonies to report upon it. My first care was to make a careful analysis of the conditions under which the alleged favourable results were realized. The Festiniog Railway, 13 or 14 miles in length, had been originally opened as a horse tramway for the purpose of connecting a large group of slate quarries with the port of shipment. For 30 years it was worked by horses, which drew the small empty trucks up the gradient from the port to the slate quarries. The horses themselves were then carried down in specially designed trucks with the loaded train, the gradients being such as to allow the trains to descend the whole length by their own gravity without any haulage. The Railway Company having practically the monopoly of carriage without competition, was able to charge 2¾d. per ton per mile for slate, whereas the rate on ordinary railways for such freight was ¾d. to 1d. The profits of the railway while it was worked by horses was such that the Railway Company was able to expend out of the profits a sum of £50,000 in making such additions to the line as rendered it capable of being worked by locomotive power, so that the original capital did not in any way represent the total cost of the railway. The cost of loading and unloading was undertaken by the respective agents of the quarry owners, and not by the Company's servants, so that there were no terminal charges. The expenditure per train mile was nearly double the average of that of the English high speed railways, and more than three times as great as that of some of the Irish railways of the 5 feet 3 inches gauge. The percentage of expenditure to receipts was also much higher than that of some of the Irish railways. The traffic was almost exclusively confined to slates, a heavy and compact article of freight, for which a small truck had a decided advantage in point of dead load. Other exceptional conditions, which I pointed out to the Secretary of State, rendered any comparison with ordinary railways utterly absurd. The Festiniog Railway was a very remunerative undertaking even when worked by horses, and it would doubtless have been easy to have established the superiority of horse power over steam power were the comparison to have been made with ordinary railways on a basis similar to that which had been adopted by the articles in the *Times*. It must be evident, however, that the rates charged to freighters, whatever they may be, cannot exert any influence on the working expenses, which must remain the same, whether the rates paid be 2¾d., or 1d., or ¾d. But supposing the Railway Company to have been forced by competition or otherwise to lower their rates to 1d., the vaunted 29½ per cent. would have been converted into a deficit, and the expenditure would have exceeded the receipts. Of course, the rolling stock on an ordinary railway has to be designed for traffic of every description, whether light or heavy, but the rolling stock that would be economical for slates would be most extravagant for cotton or hay, and the rolling stock of the Festiniog Railway, if used for any bulky articles of freight, would involve far greater dead load than the vehicles of the ordinary gauge. But the articles of the *Times* hopelessly confused the subject by mixing up the question of the live load *actually* carried, and the live load that *can be* carried by full loads. Now anyone who has the slightest acquaintance with the working of railways knows that the principal causes of dead load are due not so much to construction of vehicles or to the gauge as to the character of the traffic and the difficulty of obtaining full loads. The whole comparison was manifestly unfair and untenable, and the cost of working the Festiniog Railway, when due allowance had been made for the exceptional conditions, came out most unfavourably compared with the railways of ordinary gauge. There is no doubt that the exceptionally narrow gauge gives some advantage by allowing the use of sharper curves, but this advantage is greatly exaggerated, for the difference in resistance of a 6-foot rigid wheel base per degree of curvature on the 2-foot and the 4-foot 8½-inch gauge is less than 1 per cent. of the gross weight of the train. In flat countries, where sharp curves are unnecessary, the gauge makes no appreciable difference whatever in this respect. If we analyse the question of cheap construction, the advantage gained by a narrow gauge will be found to have been greatly exaggerated, for a large number of items of which the cost of railways is made up are not in any way affected by the gauge. For example, the preliminary expenses—cost of survey, the land, level crossings, fences, stations, workshops, staff quarters, station machinery, telegraph, plant, and rolling stock—required for a given traffic are not affected by the gauge. In the earthwork, the only difference is in the different widths of formation, the slopes of cuttings and embankments being the same. The difference is relatively less in deep cuttings or high embankments than in low embankments. In an embankment 50 feet high, the difference due to the gauge will probably be less than 1 per cent. In culverts, the two faces would be the same for both gauges, the length of barrel being merely increased by the difference in width of formation. In large bridges, for equal loads the difference would be almost inappreciable; in minor bridges the difference would be very small. The ballast and sleepers would show the greatest difference, but with equal loads there would be no difference in the weight of rails. It is evident, therefore, that, *providing similar loads are adopted in both cases*, the economy effected by the gauge alone is extremely small, and a reduction of wheel load implies reduced efficiency. But, even without a reduction of the wheel load, the smaller gauge may prove to be more expensive in the first cost. In one case in which comparative estimates were made for a branch line, the smaller gauge proved to be more expensive in consequence of the expensive transfer station, the separate workshops, and the increased reserve of rolling stock necessitated by the break of gauge. As an instance of the confusion in which this question is involved, I may mention that in 1882, when I was asked by the Government of India to formulate a general opinion on the relative cost of the mètre and 5-foot 6-inch gauge, I stated:—"It is simply impossible to lay down anything like a proportion between the cost of gauges; it will differ in every individual case." In illustration of this impossibility I assumed two very extreme cases, and I stated that the difference in those cases varied between 5 and 33 per cent. I discovered afterwards that a witness, in evidence before the Railway Committee of the House of Commons, actually named me as the authority for the statement that in a mountainous country the excess cost of the 5-foot 6-inch gauge over the mètre gauge was 5 per cent., whilst for a surface line, with but little cutting or embankment, it was 33 per cent., a conclusion utterly opposed to my real views, which I traced to an officer who had carelessly read my note, and had entirely misapprehended its contents.

The break of gauge in any country is a very serious matter, and the advantages to be gained should be very marked to justify it. It is especially prejudicial in a military point of view, as it not only gives rise to loss, confusion, and breakage in the transfer of military stores, but it also prevents the concentration, in an emergency, of the rolling stock of those railways which are not of the same gauge. It is, moreover, apt to engender a want of fixed policy, which is productive of the worst results, and both in India and the United States I have seen the exceptionally narrow gauge abandoned and replaced by the standard gauge. In one instance, I witnessed three changes of policy in one railway of 100 miles in length. First the materials were ordered out for the 5-foot 6-inch gauge, then the railway was constructed and completed on the mètre system, and finally almost a new line was constructed on the 5-foot 6-inch gauge. In fact, there were, at one and the same time, practically two railways existing, the mètre gauge carrying on the regular traffic, and the 5-foot 6-inch gauge carrying the materials for completing the broader gauge. I am convinced that the loss entailed by such changes of policy has, in many cases, far exceeded any saving that could be effected by the introduction of the exceptionally narrow gauge. Fortunately, in the case of India, it has been possible to minimize the loss by the transfer of the discarded material and rolling stock to other railways of the same gauge.

There is always a tendency on the part of managers and other railway officers, on the open line, to increase the wheel load, the size of the vehicles, the weight of the rails, and the speed. In the case of the mètre gauge lines of India, which commenced with small engines and vehicles, light rails, and slow speed, there has been a gradual but steady increase in the loads, necessitating the strengthening or renewal of bridges, the substitution of more powerful engines, larger carriages and wagons, and rails of a heavier section.

In 1870, during my absence on furlough, the Governor of Ceylon wrote informing me that the Colony had decided on the adoption of the 3-foot 6-inch gauge in an extension of the main line, which was on the 5-foot 6-inch gauge. I wrote back at once, strongly urging a reconsideration of the question, and requested that, at all events, comparative estimates should be made of the cost of the extension on both gauges. Subsequently the Governor wrote to me :—"I have completely adopted your view that a break of gauge would be a great mistake." Comparative estimates having been made, proved that the saving in first cost of construction of the 3-foot 6-inch gauge would only amount to 10 per cent., but even this saving was only in first cost, and it would have been absorbed by the cost of transferring traffic when capitalized. I may also mention that in the Colony of Victoria careful estimates were made of the cost of a railway 220 miles in length to determine the gauge upon which it should be constructed, and the comparative estimates showed that, after making allowance for the cost of transfer capitalized—for the expense of changing station, and for the additional reserve of rolling stock that would be required for a break gauge—the adoption of a railway on the standard gauge of 5 feet three inches would effect an economy of £41,000, when compared with the adoption of the smaller gauge of 3 feet 6 inches, and subsequent alternative tenders for lines on both gauges showed the economy to be effected by the adoption of the broader gauge had been under-estimated. The Denver Rio Grande Railway, about 850 miles in length, constructed on the 3-foot gauge in the mountainous portions of Colorado, has always been brought forward as an instance of the successful adoption of the smaller gauge. The traffic being chiefly mineral, and compact, necessarily renders a smaller gauge more suitable than a broad one, but on my last visit to that railway, a few years ago, I found that it had been decided to alter it to the standard gauge, and works for that purpose were in active progress.

The cases in which an exceptional gauge has been abandoned, and a standard gauge substituted for it, are somewhat numerous, and when the change is necessary, it must be done with the utmost expedition, to avoid an interruption of the traffic. If the exceptional gauge be greater than the standard, the change is comparatively easy; but to alter a narrow gauge is a more formidable undertaking.

On the Ohio and Mississippi Railway, preparations for the change of gauge from 6 feet to the standard of 4 feet 8½ inches had to be made months in advance. Fortunately the bridges were of a character that required but little alteration—as a rule, little beyond shifting the rails inwards. The sleepers were all adzed to a gauge on both sides, and the inside spikes driven to a template. The proper sleepers were put in for the new crossings, and the switch rods cut ready for the altered gauge. Where practicable, the new points and crossings were put in, but not exactly in the position of those previously existing, and this was generally managed without difficulty. The greatest difficulty was experienced at stations where the complication of points and crossings made it difficult to change with sufficient rapidity. This difficulty was sometimes obviated by the construction of temporary stations outside and completely distinct from existing stations.

For the actual plate-laying, the new rails were all laid beforehand as nearly as possible in position inside the old rails, and the line was divided into sections of five miles each, and to each section 60 men were allotted; these were sub-divided, 30 commencing at the end of the section and working away from each other. The men were in gangs of 10—3 being employed to draw the spikes, 4 to place the rails in position, and 3 to drive the new spikes.

The old rolling stock was cleared off the line at midnight on Saturday, and the work of alteration commenced on Sunday morning at 4 a.m. The alteration of the gauge for the whole distance had been completed by 11 a.m., or in 7½ hours for the whole distance of 354 miles, and before 6 p.m. on the same day trains consisting of rolling stock of the altered gauge had run over the entire line.

The alteration of gauge from mètre to the 5-foot 6-inch standard on the Nagpore Bengal Railway was a much more formidable task. The alteration of the permanent-way was simply effected by the use of new steel transverse sleepers, which were stamped with double sets of jaws, so as to hold both the lighter rails of the mètre gauge and the heavier rails of the broader gauge. These sleepers were gradually substituted for the existing sleepers under the mètre-gauge railway, and when the transfer of sleepers had been entirely completed, the new and heavier rails were laid outside the mètre-gauge railway upon them everywhere except where there were sidings, turn-outs, bridges, and a few other places. The alteration was thus easily effected, so far as the mere change of the permanent-way was concerned, but this was only a small part of the alteration. The large bridges, one of which consisted of 9 bays of 150 feet span, required entirely new girders. The change was effected by utilizing the existing girders as scaffolding to erect the new girders. Travelling cranes, running on the top booms of the existing girders, were used for the purposes of erection, and when the new girders had been completely erected outside the old girders they were used to remove the old girders in sections. The piers of the mètre-gauge bridge were fortunately of sufficient width for the girders of the broader gauge. All the girders of the smaller bridges had to be replaced by stronger girders, and all culverts and bridges, whether arch or girder, required alteration in their wing walls. The new girders, rails, and sleepers being deeper than those displaced, it was necessary to lower the bearings, and, in order to do this, the mètre-gauge girders had to be slewed from side to side, and recesses were cut in the masonry and then filled in temporarily with wood packings. For bridges of 20 feet span and under, the new girder spans were rivetted together complete at the depôt, the cross sleepers fixed, levelled, and notched to template, ready to receive the rails of the mixed gauge. A train of wagons was then loaded with them and sent out, together with a 10-ton travelling crane. On arriving at the nearest station the crane, with one or more of the spans, was taken by the engine to the bridges, the line uncoupled, the rails pulled up, the old span removed and put on one side by the crane, and the recesses in the masonry being dressed, the new span was placed complete on the bridge by the crane, and the old span picked up and replaced on the empty wagon, and the rails relaid. As many as seven bridges were thus relaid in a single working day. A large number of new bridges were required where there were diversions. The total cost of conversion averaged about £9,000 a mile. Fortunately, anticipating the possibility of a change of policy regarding the gauge of railways, I had designed the tunnels on the State railways of a section sufficient to take the rolling stock of the 5-foot 6-inch gauge. No alteration was, therefore, requisite in the only tunnel, which was 735 feet in length, in an exceedingly hard rock containing corundum.

It is equally possible with any gauge to adopt large or small vehicles, powerful or weak engines, heavy or light rails, high or low speeds. It has been sometimes urged that practically light rails cannot be used with the broader gauge; but the experience of the Duke of Buckingham's Agricultural Railway contradicts this argument. It was laid with a standard 4-foot 8½-inch gauge, with 30lb. rails. The ordinary trucks from adjoining railways are drawn by special light engines of about 12 tons at a speed of 8 miles per hour. The ruling gradient is 1 in 50, following as nearly as practicable the surface of the country. The cost of this railway, including land, was £1,400 per mile; but the tendency of managers is generally towards an increase in the size, weight, and speed of vehicles and engines, and it is probable that this line will some day be put on the same footing with ordinary railways in England.

The Manchester and Liverpool Railway, on the 4-foot 8½-inch gauge, was for many years worked with rails weighing 35lbs. per yard. The Great Western Railway, with 7-foot gauge, used a 45lb. rail with longitudinal sleepers; whilst, on the other hand, the Festiniog Railway, with its 2-foot gauge, had, at the time I visited it, a 48lb. rail, which, I believe, was afterwards replaced by a 60lb. rail. The mètre-gauge railways in India commenced with a 36lb. rail, which was gradually replaced by a 42lb. rail, then by a 50lb. rail, and the tendency is still to increase this weight.

The engines on the Manchester and Liverpool Railway, with which Pambour made his experiments, varied from 8 to 11 tons, with tenders 5½ to 6½ tons; but some of the engines on the mètre gauge vary from 20 to 24 tons, with tenders weighing from 13 to 15 tons. On the Festiniog Railway, at the time I visited it, the heaviest engine was 19½ tons.

It is necessary, however, to draw a distinction between the disadvantages of a break of gauge and the intrinsic merits or demerits of any particular gauge.

It is quite a mistake, for example, to designate the mètre gauge "a toy railway," for there is no doubt that a very considerable traffic can be carried with economy by means of such a railway. Too many, in their dislike to the break of gauge, have fallen into the error of disparaging and under-estimating the powers of that gauge, which has been obnoxious to them, and although personally

I consider the introduction of the mètre gauge into India a mistaken policy, it has frequently fallen to my lot to take up the cudgels on its behalf, and to defend it from the intemperate and unfair arguments of its opponents. But as the traffic of India is to a great extent agricultural, and consequently bulky, I am inclined to think that, apart from the question of a break of gauge, the wider gauge is on the whole better suited to India.

LECTURE II.

ESTIMATES.

The roughest and most approximate estimate for a railway when framed by an experienced engineer after an inspection of the ground, aided perhaps by a few aneroid observations, although formed on apparently slight data, will often be found to be surprisingly near the final estimate if based on previous experience in a similar country. This, however, can only be effected by men of considerable experience, not only in survey, but in actual construction, and any attempt at guessing by inexperienced men may lead to disastrous results. The next estimate, based on trial line and section, should not differ greatly from the final estimate. It would probably be rather larger than the final estimate, as improvements in alignment and grading are generally practicable in staking out. The final estimate should approximately represent the actual expenditure. Any very large discrepancy is generally due to incompetence or carelessness on the part of the engineer. An excessive estimate is quite as great a proof of incompetence on the part of the engineer as an insufficient estimate, and, indeed, it is attended with more mischievous results, for if an excessive estimate be made and sanctioned, the amount estimated will as a rule be expended. An exceeded estimate is frequently due to a want of system, of close check on minor details, and a failure to keep a proper analysis of the details of cost in each item of expenditure. It is also often due to an improper reliance on inexperienced assistants, and to defective information regarding the state of the estimates. Sometimes it happens that the engineer assumes the rate of execution of the earlier portions of the work to represent the average rate throughout, forgetful of the fact that as a rule the further the work progresses the higher will be the rate for execution. For example, in a deep, rock-bound cutting, the rate of cost per unit in the deeper portions may prove to be double that of the first opening out of the cutting. Again, in a high embankment formed from side cutting, the cost of the upper portion will be very largely in excess of that of the lower portion, not only in consequence of the additional height to which the earth must be raised, but also of the greater distance from which it has to be brought, and possibly from the greater depth of the side cutting, which may entail additional expense in keeping it free of water. The ultimate cost, therefore, must not be judged to be proportional to the *quantity* of work executed, but to the *relative character* of the work executed and that to be done. I have found a very useful rough check in the form of a printed monthly return to be filled in by the executive engineer in each district. In this return each separate item, whether cutting, embankment, culvert or bridge, etc., has a lump sum allotted to it, with a column showing the decimal proportion of the total work executed to date; this proportion being determined on inspection of the character of the work done or yet to be done, and not solely by the quantity. For example, although a cutting might be half finished as regards *quantity*, if the remaining character of the work were more expensive than that done, the decimal proportion done might be represented by ·4. Every item having thus been worked out on this basis, the total can be compared with the actual expenditure to date. The engineer in his visits of inspection is able readily to check the decimal proportion which may have been adopted by his executive, or assistant, engineer, especially when he has the measurements to assist him. For want of such checks on expenditure, it has fallen within my experience that an engineer has sent in an application for a very large increase to his estimate two months after he had reported officially that he was working well within the estimated rates. Such a want of proper control is inexcusable in an engineer.

Excesses due to want of foresight or care in the preparation of estimates, or to neglect of proper control or supervision, form fair ground for dissatisfaction and reprehension; but a careful examination should be made to ascertain whether they arise from such causes. Too stringent dealing with excesses, where they can be shown to have arisen from causes that could not have been foreseen or guarded against, is apt to lead to the preparation of excessive estimates, and the rise of rates in a district has sometimes been due to the action which forces the engineer to prepare estimates at rates calculated to cover every *possible* rather than every *probable* contingency.

In framing estimates for railways, it is of great assistance to tabulate expenditure under the following heads, which may be divided into sub-heads :—

Preliminary.
Land and compensation.
Earthwork.
Large bridges.
Minor bridges and culverts.
Tunnels.
Level crossings.
Ballast.
Sleepers.
Permanent-way.
Station buildings.
Staff quarters.
Temporary quarters.
Offices.
Station machinery.
Workshops.
Workshop machinery.
Telegraph.
Rolling stock, establishment, contingencies.

In preliminary estimates much time and trouble is saved by the preparation of type drawings and diagrams, and tables of quantities of earthworks, bridges, culverts, different heights in embankment or cutting, and for approximate corrections for side-long ground, etc., etc. But it cannot be too strongly impressed on the engineer that the only way of making a satisfactory *final* estimate is to go thoroughly into every detail, working in a definite and systematic manner, and avoiding as far as practicable all guesses and uncertainties.

The final estimate is usually made after the line has been staked out, trial pits made, borings sunk to ascertain the character of the cuttings and the depth of the foundations, and when all the detail drawings have been prepared. The trial pits determine the slopes to be adopted in cuttings, and the borings determine not only the depth of foundation, but the character of the bridge to be adopted. Before any final estimate can be safely made, it is necessary to examine thoroughly the district through which the railway is to be made, in order to ascertain its resources in ballast, brick earth, lime, sand, stone quarries, fuel for brick making, water supply, etc., and to make the necessary experiments to determine the suitability of such materials for railway purposes.

CURVES AND GRADIENTS.

The selection of ruling gradients and curves has an important bearing upon the ultimate working expenses of the line. It depends to a great measure on the physical features of the country, and it is necessary to weigh carefully how far exceptionally sharp curves and steep gradients should be adopted. The saving in first cost effected must be carefully balanced by estimating interest on the additional cost of work necessitated, compared with the annual increase inflicted upon the working expenses with an assumed traffic. This is necessarily a question of some uncertainty, because many of the factors involved are indeterminate. As a general rule, it may be said that it is undesirable to adopt a steeper gradient than 1 in 100 for single engine gradients, or 1 in 40 for double engine gradients. It is better to avoid the division or breaking up of a train; and a gradient of about 1 in 100 or 120 will enable a single engine to draw to the foot of the double engine incline such a train as it will, with the assistance of a heavy incline engine, take up a gradient of 1 in 40 at the diminished speed generally necessary on a double engine incline.

The ruling gradient, of course, limits the useful load that an engine can take, but when a ruling gradient has been adopted on any section of railway, it may be used freely in that section to save work, because the adoption of short rises and falls, which do not involve the use of breaks, does not materially increase the working expenses. This, however, is not the case with *curves* of minimum radius, which should not be used if the saving effected by them is but slight. The use of curves of fairly large radius, however, does not materially affect the working expenses, and it is a great mistake to incur heavy expense for the sake of adhering to a dead-straight line.

It is very desirable to make allowance for the retarding influence of curves on the ruling gradient by flattening it where they occur, but this is useless unless it can be done with every curve of minimum radius that occurs on the ruling gradient. This becomes practically impossible on those inclines which are laid out mainly in curves, for if a single curve of minimum radius be on the ruling gradient, it limits the tractive power of the engine, thus practically ruling the load throughout that section.

It is very necessary to insert a short piece of straight between every reverse curve. An object-lesson on this point was gained on the Ceylon incline, over which some runaway wagons passed safely for several miles of almost continuous curve, but ran off the rails at the only place at which the precaution of inserting the prescribed length of straight between two reverse curves had been inadvertently neglected. When exceptional gradients are adopted, it is desirable to confine them as far as practicable to one incline or group of inclines; scattered lengths of exceptionally steep gradients involve difficulty and expensive working, and the adoption of exceptionally sharp gradients in both directions gives rise to complication.

In a double engine gradient, if the incline is fairly continuous, the safer plan is to work with one engine pushing, the more powerful engine being in front. With two engines in front of a train the strain on the draw-bars is so severe that the train may part and cause a serious accident from escape of the vehicles down the incline.

For pushing, the train should be furnished with a self-acting signal, actuated by compression of the buffers near the middle of the train, so as to indicate to the driver whether the following engine is doing more or less than its fair share of the work.

As an object-lesson, I may mention that the front engine on an incline of 1 in 45, going round a sharp curve of 660 feet radius, suddenly ran into a landslip, and the driver of the following engine, unaware of the fact, did not shut off his steam; but the only result was that the buffers were compressed, and the engine puffed heavily and stopped without doing any injury.

In descending the incline, the two engines should be placed in front. In Ceylon the system of breaking for the descent of the incline was arranged by hanging 56lb. weights on the break levers of the wagons in sufficient number to hold the train on the incline, thus leaving the engine, tender, and brake-van brakes available in case of any emergency. This system was in operation for more than 20 years without a single failure.

On one incline in India worked on this system, I adopted a short "test incline" of the same gradient as the main incline, followed by a short piece of level, the object of which was to enable the engine to draw up before entering on the main incline and add more weight should the amount of weight hung on the breaks be insufficient to require a slight haulage on the test incline.

When the natural features of the country are such as to prevent the easy construction of a locomotive gradient, it may be necessary to have recourse either to the expedient of corkscrew loops, as on the St. Gothard Railway, in which the line crosses over itself in order to gain length for an even gradient; or to adopt a rack railway, as in the Hartz Mountains; or a rope incline, as in the Sao Paulo Railway; or reversing stations, such as those adopted on the Great Indian Peninsula Railway. The corkscrew system is generally very expensive, involving, as a rule, considerable length of curved tunnels, but in some cases, where the country lends itself to this mode of construction, it may be adopted with advantage.

Although gradients of 1 in 25, or even steeper, are occasionally worked by ordinary locomotives, the tractive power of which is dependent upon the adhesion of the wheels, yet in gradients much steeper than 1 in 40 it becomes so expensive as to be almost prohibitive, because the weight of the engine necessary to secure proper adhesion is so great that a large portion of the power is consumed in raising its own weight, especially in those countries which are exposed to frost.

The most improved form of rack railway is the "Abt-system," in the locomotives of which the adhesion and the rack gear can be used either separately or in combination, so that on level portions of the line the engine may run at higher speeds working by adhesion only, but using the adhesion and rack in combination on those portions of the line where the rack is laid.

In a comparison I made between the Abt engine and a double bogie engine working in the ordinary manner by adhesion, the whole weight being available for adhesion, I found that taking $\frac{1}{11}$ as the co-efficient of adhesion in frosty weather, the comparative efficiency of the two engines was as follows:—On a gradient of 1 in 40 the relative efficiency of the Abt engine was 2·57 to 1, on 1 in 25 it was 3·16 to 1, on 1 in 20 3·74 to 1, and on 1 in 15 6·11 to 1. The co-efficient of adhesion sometimes falls far below $\frac{1}{11}$ when ice has been formed on the rails. Of course, it may be increased by the use of sand, but this entails wear of rails and tyres.

Figs. 2, 3, and 4, *Plate* VII., show the form of the rack and its relation to the rails. *Fig.* 5 shows a single rack-bar. The number of racks may be varied according to the load to be taken. For example, if three racks be necessary on a gradient of 1 in 16, one of the racks may be dispensed with on gradients of a somewhat lighter character. It will be seen that the rack bars are "staggered," that is, they are so arranged that the teeth of one rack are slightly in advance of those of the adjoining rack; the racks being separate and in short lengths, can easily be taken out and replaced by others in a few minutes in the event of accidents or wear of teeth.

Figs. 7, 8, and 9, *Plate* VIII., give a general idea of the locomotive, the details of the pinion being shown at *Fig.* 10, *Plate* VIII. The teeth are on three separate rings, any one of which, in case of injury, can be replaced in a short time without difficulty. The diagram at the bottom of *Plate* VIII. represents the wear of the pinion teeth of the locomotive after seven years' work and 68,000 miles' run on the Hartz Mountain Railway with ruling gradients of 1 in 16½.

Based on the experience of seven years, it is estimated that the teeth of the pinion will last twelve years without the necessity of renewal, and those of the rack more than 100 years.

Figs. 11, 12, and 13, *Plate* IX., show the details of the entering tongue, which is supported on springs; the teeth being cut away near the point of the tongue to allow the pinion to enter the rack without jar. *Fig.* 14, *Plate* IX., shows the arrangement at points of crossings, but as a rule such an arrangement is unnecessary, as points and crossings should, if practicable, be arranged to be nearly, if not quite, on the level, or at all events on such a gradient that the rack may be dispensed with. The wear of the rails on an incline worked on the Abt system is very much less than when worked by the ordinary system; the slipping of wheels is to a great extent avoided, and the use of breaks on the rails is greatly lessened, because so much of the breaking can be done by means of the rack and pinion. An experimental line on the Abt system was laid down in India on a gradient of 1 in 25, but the experiment was altogether mismanaged. The length of the line laid down (only one mile) was too short for the purpose of experiment; the speed was greater than that for which the engines were designed, and in most of the experiments it was got up before reaching the rack, so as to take the incline with a rush, and on one occasion the experiment was so carelessly conducted that the pinion, on entering the rack, was in backward gear while the adhesion cylinders were in forward gear. It was impossible, therefore, to deduce any practical conclusions from an experiment thus conducted, but the Hartz Mountain Railway, with its gradients of 1 in 16½, has proved such a success that a large number of railways have been constructed on the Abt system with minimum curves varying from 100 to 600 feet radius.

Although, in some mountain lines for passengers, gradients of 1 in 4 have been adopted, 1 in 15 or 16 would, I think, appear to be about the practical limit of the Abt system. In cases where the question of the ordinary or the rack system has to be decided, the relative length must be taken into account. It is not in all cases, however, that a saving in length can be obtained by a steeper gradient. In a mountain range the length may be in direct proportion to the gradient, and the saving in first cost, in time of ascent, in safety of working, and in economy of maintenance and general expenses, may turn the scale in favour of a shorter but steeper ascent. One advantage of the Abt system is that as the machinery working the rack is entirely distinct from that which works the ordinary wheels, the rack can be discontinued where the gradient does not require it, and the locomotive can run at higher speed on those parts. The quadruple blast at slower speed, when the pinions are at work, enables steam to be made as rapidly as when the engine is travelling at a greater speed.

In the Bore Ghât and Thul Ghât, in India, are to be found instances of the adoption of zig-zags with reversing stations, where the natural features of the country have rendered it difficult to carry out a continuous gradient. The ruling gradient of the Bore Ghât incline is 1 in 37. *Plate* X. will give a fair idea of the reversing station. The arrangement is, however, one which should be avoided if possible; it not only entails loss of time in changing the engine from front to rear of the train, but it involves a considerable element of danger from over-running the end of the reversing station in slippery weather, should the driver happen to lose control of his train; for when once a train on a steep incline has exceeded a certain speed, it becomes exceedingly difficult to regain control.

Plate XI. shows the results of an accident from this cause. Fortunately this accident occurred to a goods train, and the loss of life was comparatively small. I may add that the train in which the Government inspecting officer was conveyed to the spot to investigate the cause of the accident was in some danger of a similar accident, the driver having lost control of his train and regained it with some difficulty. Since that time a catch siding has been constructed a short distance above the reversing station. This siding is on an extremely sharp gradient, rising in a direction opposite to the fall of the main incline, and unless a descending train is brought to a stand-still before reaching its points, it is turned into the catch siding. It is questionable, however, whether this would not be an element of danger if the train out of control should acquire a very high speed. The sudden switching out sideways, combined with the reversal of the gradient, would be very liable to wreck a train at high speed.

The employment of continuous breaks on this incline has, however, rendered it far less dangerous. A zig-zag should, however, always be avoided if practicable, and in most cases it may be avoided somehow or other.

A very sudden change of gradient descending on to a bridge should be avoided. Bridges are frequently at the lowest point of that portion of the line in which they are situated, and thus it often happens that a bridge is the natural place for a change of gradient, and when this is the case there should, if possible, be a short portion of level, or nearly level, of sufficient length to take the whole of the train before the bridge is reached.

Under conditions of a special character it may be desirable to have recourse to a rope incline, of which the Sao Paulo incline in Brazil is a fair specimen. The country at a short distance from the coast rises abruptly by a precipitous escarpment to a plateau of 2,700 feet above the level of the sea. This escarpment has been surmounted by a series of inclines, each varying in length from 6,000 to 7,000 feet, extending over 5 miles, at a gradient of 1 in 9¾. The length of a locomotive line of 1 in 40 to reach the same point would be about four times its length, its cost about three times as great, the time occupied in ascent 2¼ times as great, and the working expenses about the same.

It does not, however, always happen that a saving in length can be effected by an exceptionally steep gradient. In ascending the mountain zone of Ceylon I found that a steep rope incline would effect no saving in length compared with a locomotive incline of 1 in 45.

The Sao Paulo incline is worked on the "Tail-end system," in which one train takes down one end of the rope whilst the other end ascends.

The line has three lines of rails on the upper half of the incline and two on the lower portion, below the passing place, as shown in *Fig.* A, *Plate* XII., at **A**. The arrangement of the engine head is shown at **B**, *Plate* XII. The length of the train is limited to three wagons and the incline-brake-car, the gross load being 40 tons, and the paying load only 21 tons. The capabilities of the incline are limited to about 1,700 tons per day of 10 hours; the rope is 4 inches in circumference.

During the construction of the Kojak tunnel in Beluchistan it became necessary to have recourse temporarily to a very sharp rope incline, so that the construction of the railway might be pushed forward for military purposes, pending the completion of the tunnel. The steepest of these inclines was 1 in 2½, with a vertical rise of 600 feet; the descent on the other side was 1 in 2¾. The wagons were shunted on to a specially designed incline car, capable of bearing one wagon only (or a locomotive if required), on a horizontal platform as shown in the diagram at **E**, *Plate* XII. As it was of importance to complete the work in the least possible time and in the most inexpensive way, it was decided, in order to save rock cutting, to avoid the use of self-acting switches, and to simplify the shunting arrangements at the top and bottom of the incline, that two distinct lines of rail should be laid, the centres of which were only 6 inches apart, except where the cars passed each other as shown at **C**, *Plate* XII. At the point **a**, the rope was allowed to drop into a gap in the rail, as indicated in the diagram in detail at **a**, *Plate* XII., assisted to do so by tapering wood guides, and the two sets of rails were carried on two longitudinal baulks, shown at **D**, bolted down to concrete blocks. The rollers were about 30 feet apart, but vertical rollers were only used at, and about, the passing places, the incline being perfectly straight elsewhere. The rope was 4½ inches in circumference, was worked by means of a locomotive engine temporarily made stationary at the summit of each incline, and geared down to give proper speed with a Fowler clip drum. The arrangement was in operation for three years, the maximum amount carried by it in one direction being 45,000 tons in a year, 6,000 in a month, and 580 in a day.

To put any system of hand brake on the car would have necessitated a brakesman on the car, and a self-acting brake would, in my opinion, have involved a risk of accident, and as the incline was designed only for the railway materials and munitions of war, I decided that the cars should not be furnished with any brake arrangement, and that on no account was any person to be allowed to travel upon the car.

Rope traction has been used with various satisfactory results for tram-cars in streets. The rope is carried in a conduit below the street, and supported on pulleys at intervals, and the cars are connected to it by grips which pass down into the conduit through a slot in the roadway between the rails. The conduit itself is generally constructed of concrete, and the depth varies from some 16 inches to about 3 feet. The slot, which has a width of from ¾ to 1¼ inch, is formed of rolled bars of a Z or L section, supported every three or four feet on cast-iron or forged yokes, to which they are firmly bolted. Sometimes the running rails are connected to extensions of these yokes, whilst in others they merely rest on the concrete bed and are connected by means of tie bars at intervals to the slot rails. *Fig.* 1, *Plate* XIII., shows the section of the concrete in use at Washington, U.S.A. Here the cast-iron yokes are very massive and the conduit is deep, having a lining of iron plates. The yokes weigh over 3cwt. each. *Fig.* 2, *Plate* XIII., is a section of the cable conduit at Birmingham. The yokes are built up of steel T bars stamped to required shape. *Fig.* 3 is a section of the conduit at Brixton. These yokes are of cast iron and weigh rather less than one hundredweight. In all these sections one-half shows the yoke and the other half-section is through the intermediate concrete. The black circle shows the position of the rope on the pulley, whilst in No. 2 the upper circle shows the position of the rope when in the grip. The slot rail in No. 3 is the patent of Mr. Colam. The cable varies from ⅞-inch diameter in short lines to about 1¼-inch diameter in larger lines, and can be easily worked to a distance of two miles from the power station, or about four miles of rope. The ropes are of medium quality of steel with a hemp cord to give flexibility, and with "Lang's lay."

"Locked lay rope," that is, with special section of wire formed so as to interlock, has been tried, but I believe difficulties were experienced in its use, chiefly in splicing.

The cable is supported on two classes of pulleys, generally known as "carry pulleys" and "curve pulleys." Carry pulleys are used to support the rope on straight portions of the line or on very flat curves; they are usually from 12 to 18 inches diameter on the bearing surfaces, and run on a horizontal axis at right angles to the slot. *Fig.* 4, *Plate* XIII., shows one of these carry pulleys and the man-hole and pit for its accommodation. *Fig.* 5 gives a similar view of a curve pulley. This is used on curves to keep the rope from coming in contact with side of the conduit. It is drum shaped, rather wider at the top than at the bottom, where it has a wide flat flange. It runs on a vertical spindle, and is provided with a lubricating cup at the top. Such pulleys vary in diameter from 12 to 24 inches, and, as well as the carry pulleys, should be as light as is consistent with strength. Close to the upper end of this pulley a flat bar is shown. This is intended to act as a guide to the grip and take any side thrust there may be on it owing to the tension of the rope round the curve. Carry pulleys are spaced from 30 to 40 feet apart, whilst the curve between them does not exceed 2 inches. All these pulleys must be arranged so as to allow of easy lubrication and replacement. The position of the cable in the conduit is generally rather on one side of the slot, so that any dirt falling through may fall clear of the rope.

In addition to the man-holes at the pulley-pits, there are also usually small hatches at two or three points in the line to allow of extraction or getting at the grip. The slot points and crossings for a cable rope are too complicated for description here. The chief point of difficulty to be overcome is the support of the moveable tongue, which must necessarily have a very long overhang, and yet be capable of supporting the heaviest traffic in the street. The grip by which the cars make connection with the constantly moving cable is one of the most important points in the cable tramway. Its design must be settled at a very early stage, as it regulates the size and depth of the conduit, the height of the cable, and the various appliances which must be provided.

Grips of all patterns and methods of closing have been tried, but the most successful have been those known as "side-grips," that is, with the opening at the side, the cable being held between the upper and lower jaw. *Fig.* 6, *Plate* XIII., shows a side-grip, as used on the Birmingham line. Here the upper jaw is a fixture, and held by two side pieces shown in the other view of it (*Fig.* 7). The lower jaw, fastening to the centre plate, is moved up and down by means of two levers. The first has a range of about 3 inches in motion, whilst the second has a much smaller but more powerful range, and is capable of adjustment so as to grip the rope very firmly. The second lever alone is used for controlling the car, the first being used for picking up or dropping the cable at the beginning or end of the line, or when changing from one rope to another, as at the centre of the line. The grip jaws are lined with easily removeable liners of steel or cast iron; the latter is preferable, although it has a shorter life, because it wears the cable less. On each side of *Fig.* 6, and in the middle of *Fig.* 7, is a small running piece; this, too, is usually of cast iron and easily renewable. It rubs against the guard on curves, as shown in section No. 5. Small pulleys have been tried on grips to take the weight of the rope off the line when the grip is open, and the car consequently at rest, with the idea of minimizing the wear of them, but these small pulleys very soon clog with dirt, and stick and become useless, and as they entail an extra width of conduit and greater clearance for the grip, their use is disadvantageous.

When it is required to pick up or drop the cable from the grip, as at the end of the line, or when changing from one rope to another, it is usual to slew the tramway, and with it the slot, to one side for a short distance, so that the rope will be drawn into or out of the grip as the case may be. *Fig.* 8, *Plate* XIII., shows a plan of such an arrangement, the line of the rope being dotted. The methods of driving the rope vary. In America the rope usually passes several times round two drums, one or both of which are driven by the winding engine. *Fig.* 9, *Plate* XIII., shows such an arrangement. The objections are that the tension of the rope on the first groove being greater, and the wear thereon being also greater than the remainder of the grooves, there is what may be termed a back tension set up in the rope, causing great wear both to the rope and to the drum, and consequent loss of power. To obviate this the drums are sometimes made in two pieces, each having three grooves, and these two halves connected by a jack-in-the-box, or arrangement of 3-bevel wheels, to equalize the tension. Walker's differential pulley is another method of meeting this objection. A section of the view of this pulley is shown in *Fig.* 10, *Plate* XIII. Here the several grooves are each formed on a separate ring which fits to the turned drum of the pulley. One flange is loose, and can be closed up by means of bolts, thus pressing the rings together and giving the necessary friction required to drive the rope in grooves, while at the same time allowing independent motion when any individual rope is unduly strained. In England the method shown in *Fig.* 11, *Plate* XIII., is usually adopted. Here are only two single groove pulleys, and the rope passes round them in a S. Both pulleys are driven, and they usually overhang their bearings so as to facilitate putting the rope round them. The grooves of the driving pulleys are usually filled with some substance to give a good grip on the rope, while not hard enough to injure it. Wood, rubber, leather and rope have been used with success, and I believe also that white metal has given good results.

On leaving the driving pulleys the rope passes to a tension gear, the object of which is to keep the rope tight, and at the same time to give the necessary tension to the driving pulleys. It also serves to take up the slack of the rope as it lengthens in use. A tension gear is shown in *Fig.* 12, *Plate* XIII. It consists of a large pulley mounted on a truck and running on a straight track. On the track is also mounted a crab, to which the tail rope is fastened. This tail rope passes over a pulley supporting a weight, or being attached to a spring at the end of the track. By means of the crab the motion of the weight or spring can be adjusted as required to take up the slack as the cable stretches, and thus to reduce the range of motion of the weight or spring. A long cable will stretch 50 feet in a very short time after being put to work, and pieces have from time to time to be cut out and the ends re-spliced as the cable continues to stretch.

All the driving pulleys and pulleys round which the direction of the cable is altered more than a very few degrees should be of large diameter, otherwise the rope is very soon destroyed. Round sharp curves it is sometimes necessary to run auxiliary cables which are driven at rather slower speed off the main cable.

There are numerous points requiring special apparatus, such as crossing of cables, automatic release of the grip, holding-down pulleys at valleys between gradients, but it is impossible to attempt to describe fully the ingenious arrangements which have been devised, and which are found to work well in practice. Cable tramways are best suited to a frequent traffic in which cars follow one another at intervals of a few minutes; and where the gradients are heavy, the rope being endless balances the ascending by the descending cars, so that the average power required is very little in excess of that required for a level road.

EARTHWORK.

It is a mistake to attempt to economize by narrowing too much the formation-width of embankments, especially when ballast is expensive, for it leads to great waste of ballast, which, in packing the permanent-way, is lost down the slopes if sufficient margin be not allowed for it. In England, where land is too expensive to construct embankments out of side cutting, the equalization of cuttings and embankments is of importance, but in India and other new countries, where land is comparatively valueless, such equalization is unnecessary. Embankments are chiefly constructed from side cutting, and unless they are very high the use of tip-waggons is expensive, and the contents of cuttings often go to spoil. Tipping, moreover, is essentially a slow process, for the work can only be attacked at one end, whereas embankments formed out of side cutting can be commenced at all points simultaneously and thrown up with great rapidity. When there is a long stretch of embankment constructed from side cutting, the side-pits should, as a rule, be in disconnected sections, separated by a partition of unexcavated material to prevent any rush of water parallel to the line, which may underscour the toe of the slope. But a too rigid adherence to this plan may be inconvenient, as in some instances it may be necessary to connect the pits so as to concentrate the drainage and pass it to a bridge or culvert.

When this is the case the connection should be, as far as possible, from the toe of the embankment, as shown at A, *Plate* XIV. The bottom of the side cutting should generally slope away from the railway, and a good berm should be allowed between the side cutting and the toe of the slope, and the side cutting itself should always be trimmed off to a suitable slope.

Clay in earthworks is often a source of great trouble and difficulty, especially that type of clay which is termed the London clay. George Stephenson used to say of it that it would rather run up-hill than stand still, and this is scarcely an exaggeration. I remember one instance on the Crystal Palace low level line, on which I was engaged, where a high embankment was tipped out of a London clay cutting during a very rainy autumn which had succeeded a very dry summer. The embankment assumed the form shown in the diagram at BC, *Plate* XIV. A heavy retaining wall built at B, to arrest the progress of the slip, was pushed over, and I was obliged to open out trenches almost to the heart of the embankment, which I filled up with chalk brought in trains from a distance, thus forming at once counterforts and drainage. The viscosity of this clay may be imagined from the fact that in cutting one of these trenches under what had been the original slope of the embankment, I found that some of the gravel that had been used at the top of the embankment as temporary ballast during construction had actually found its way down to the original surface of the ground as shown at **C**, *Plate* XIV.

In cuttings, slips are frequently caused by the accumulation of water in catch drains, to which no proper outlet has been provided. Sometimes in side-long ground I have carried the catch drains up the hill-side, as shown at **E** and **E**, *Plate* XIV., in longitudinal and cross-section respectively, thus not only keeping the drain further from the cutting, but also giving it a much steeper outfall than could be obtained by keeping it in the usual manner close to the top of the cutting, as shown at **D** and **D**. In a long cutting the catch drains should be puddled and connected with the cutting at intervals by large open half-round tile drains, or by paved water-courses carried down the slope. Under certain conditions it may be desirable to omit catch drains altogether.

Slips on side-long ground are, of course, much more likely to take place when there is a general dip of the strata in the same direction as the natural slope of the ground. It is, therefore, of great importance when constructing a railway on the flanks of a valley to study the different strata, and unless there should be some strong reason to the contrary, to select that side on which the dip is most favourable. The diagrams **F** and **G**, *Plate* XIV., being assumed as typical cases where, at **F**, the dip of the strata is in the same direction as the general slope of the ground, and it would consequently be liable to heavier slips than at **G**, where the dip is opposed to the natural slope.

Plate XV. illustrates the case of a slip owing to an almost imperceptible seam of clay in the rock.

The subject of slips in earthworks is one of great difficulty, which, as a rule, receives from engineers less attention than it deserves. In dealing with slips, as in most questions connected with engineering, there can be no hard-and-fast rule of proceeding. Each case requires study, special treatment, and the exercise of common sense. In high embankments formed of hard materials the slopes should not be less than 1½ to 1, or, in small embankments, 1¼ to 1. Small embankments and cuttings in clay may stand at a slope of 1½ to 1 when the height does not exceed 10 or 12 feet, but with the greater height flatter slopes are necessary, and slopes of 2 or even 3 to 1 are often needed. In London clay I have known the slopes of a deep cutting to be as flat as 4 to 1.

Deep cuttings and high embankments, however, should not be dressed off to one uniform slope, but should be steeper at the upper portion, flattening out towards the base, as indicated at **A**, *Plate* XVI.

Cuttings in sound rock may stand almost perpendicular, but where the strata are inclined the slope on one side of a cutting may be comparatively steep, when it may be necessary to have a very flat slope on the other side. Indications of the slope of different strata, as well as their character, should be carefully studied in any trial pits that may be made, and the slopes be determined accordingly. But the ultimate slopes to be adopted and the manner of dealing with them can only be decided, in many cases, after opening out the gullet of the cutting. Some soils, especially those liable to scour with water, will stand better with a steep slope than with a flat one.

The chief object to be obtained in dealing with slippery ground is to provide, as far as practicable, free drainage to prevent the lodgment of water, and in some cases to protect the slopes from the action of the weather and the alternating effects of frost, rain, and sunshine.

In material of the character of London clay, a vertical excavation, if left to itself for any length of time, is apt to develop a wonderful faculty for slipping. The ordinary plan of running a gullet with almost vertical sides for taking out a cutting gives free play to this tendency. As a general rule, the development of cracks in the clay during dry weather allows lodgment for water, and the slips commence somewhat as indicated roughly at **B**, **C**, **D**, **E**, *Plate* XVI. The first slip—a mass somewhat of the shape indicated at **B**—possibly scoops out the clay below the formation level at **C**, from which the pressure has been taken off by removing the clay from the gullet. Water will then accumulate in the rear of the detached portion, and will soak into the crevice between the slip and the solid ground, exerting to a certain extent hydrostatic pressure, and acting as a lubricant in facilitating the descent of the mass. In dry weather the fissure has a tendency to open more and more, and the process is repeated. As soon as the pressure is unbalanced by the removal of the *débris*, a second slip is developed at **D**, and so on in succession at **E**, until at length clay, that might have stood at $1\frac{1}{2}$ or 2 to 1 if the slip had never been allowed to develop, may assume slopes of 4 or 5 to 1 if left alone. When once slips have begun to develop in this material the only remedy is to run in trenches at intervals, taking care to go below the bottom of the slip, as shown at **F**, *Plate* XVI, filling in the trenches with broken stone, or chalk, or slag; cinders, ballast, brick rubbish, or any other suitable material, and even fascines, are sometimes used. In such cases it may be desirable to follow as nearly as possible the lines which the slip itself has taken, but to weight the lower portion so as to balance the pressure, and after cutting the necessary trenches and filling them in partially with hard material; a portion of the materials which have slipped, if it be not mere slurry, may be restored somewhat as indicated in the diagram, the upper line indicating the material replaced, the middle line the line of slip, and the lower line the excavated trench partially filled in with broken stone, etc., which should then be covered up and made even with the rest of the slope. In some cases it may be desirable to pave the bottom of the trenches before filling in the dry material, or to lay some ordinary porous drain pipes below. A bold policy in this respect is the least expensive in the long run, and these trenches will act a double part of drains and counterforts. Where suitable material is expensive or difficult to obtain, some of the clay from the slip may be burnt in the trenches, and in those cases where burnt brick earth is required for the permanent-way of a railway, it is very advantageous to have it burnt in trenches on the slopes of any clay cutting that is likely to give trouble, for the operation of burning the ballast has a two-fold effect of drying the slopes and hardening them to resist the tendency to slip. Clay embankments which have shown a tendency to slip have sometimes been greatly improved by burning the clay at the toe of the slope. Perforated pipes have been sometimes inserted into the sides of the cutting for drainage, and sometimes ordinary porous drain pipes such as those used for the drainage of land have been laid down below the surface parallel to the slope, as shown at G, *Plate* XVI., the trench in which they are laid being partly made up with sand or gravel and then made uniform with the rest of the slope with a covering surface of clay. Sometimes tarred wooden conduits filled with stones have been used in this way. Frost is a very potent factor in the commencement of slips, and some soils may be improved by soiling or by a layer of gravel or ballast. For cutting in clay which behaves in the manner I have described, it may be desirable not to work by gullet, but to take out the whole width of the cutting in layers; the slopes should not be one regular slope, but follow more nearly the typical form that the slip would naturally make for itself, as indicated at F, *Plate* XVI. Of course, the mode of working by gullet is most economical if the material of the cutting is to be tipped, but it may be less costly in the long run to prevent the development of slips, which, when once commenced, can only be checked with difficulty, and where the material from cutting is thrown to spoil it would be far better to take it out by layers extending over the whole width of the cutting and slope.

But slips in cutting are by no means always developed during construction. Sometimes they are due to disintegration or chemical changes in the constituent parts of the soil, and do not develop until years after the cutting has been completed. Other cuttings, on the contrary, which have manifested every indication of slipping during construction, have become stable when the soil has been drained of water.

Some clays seem to change their character entirely after having once been thoroughly dry. I once experimented with clay that had been brought up from a depth of 70 feet below the bed of a river. It was most tenacious, and could be cut with difficulty, and so long as it remained under water it retained this character. When taken out of water it hardened like a stone, but when once it had been thoroughly dry it would, when again immersed in water, disintegrate like brown sugar, and in the course of a few minutes be dissolved into an impalpable mud. Some deep cuttings on the Punjab Northern Railway were made through a similar material which had become dry. It was worse than rock to deal with, almost as hard, but blasting had little effect upon it, yet when water fell upon it it melted away. Vertical sides are preferable in such a material.

Slips in gravel, or material which would otherwise naturally stand at a fairly steep slope in cutting, sometimes occur from the effects of underlying water-bearing strata of sand or marl, which, in escaping, undermines the material above it, but which, if restrained and prevented from escape, would support the over-lying strata. In such cases a light wall with plenty of weep holes may be adopted for retaining the sand, as shown at H, *Plate* XVI. When the water-bearing stratum is thin, it may sometimes be treated by benching back and draining by half-round tiles or paving, as indicated at J, *Plate* XVI., the sand being restrained by a covering of loose stone. Rock cuttings, which might otherwise stand at a steep slope, sometimes fail from a similar cause, and when this occurs walls may be built under-pinning the rock and retaining the water-bearing strata, as shown at K, *Plate* XVI. But in all such cases weep holes should be provided. In some cases a retaining wall may be built at the foot of the slope, filling in the space behind it with hard dry material, well punned in layers inclined in an opposite direction to that of the slope, and properly drained, as shown at L, *Plate* XVI.

In some troublesome cuttings trenches are sunk parallel to, but at some distance behind, the slope, as at **M**, *Plate* XVI., and filled or partially filled with loose material, sand, or gravel, in order to free the soil from water, but in the case of long cuttings the trench must be connected at intervals with the cutting by cross-trenches of a similar character, the main trench having a proper inclination towards the cross-trenches to prevent the lodgment of water. Above the dry filling the trench may again be filled in with ordinary material and puddled at the top to prevent the entrance of surface water.

It should be remembered that when the stratum dips and is interspersed with veins of water-bearing silt or slippery clay, all calculations for retaining walls, based on the ordinary angle of repose for that particular soil, may be entirely at fault if the angle of the dip be parallel, or nearly so, to the natural slope of the ground, as indicated at **N**, *Plate* XVI., for the retaining wall may have to support an indefinite weight of soil. In the cuttings of the L. & N.W. Railway, close to Euston Square, where the land is expensive, the clay has been retained by walls strutted overhead, as at **O**, *Plate* XVI., the walls being inverted below. In other positions, where the cutting is not so wide, the wall is supported at intervals with counterforts, as at **P**, from which brick arches and inverts spring. In other cases, especially in shaky rock, cut and cover may be adopted which consists of arching over the cutting and filling it in above the arch. An instance of this, termed "cut and cover," is shown in *Plate* XVII. Soil of the character of London clay should not be tipped in very rainy weather, otherwise it will be almost impossible to rid it of water, and constant slips will be the consequence. A high embankment should be formed in separate layers, the surface of each layer be slightly rounded off so as to throw off the rain, and left some time for consolidation and drying before the next layer is super-imposed. Drain pipes should be inserted at intervals, as indicated in the diagram at **X**, *Plate* XVI. When an embankment is on side-long ground it is necessary to bench the ground, as indicated at **Q**, *Plate* XVI., but such benching should be properly drained so as to prevent the lodgment of water. Different forms of drains in cutting are indicated in diagrams **R**, **S**, **T**, **U**, **V**, and **W**, *Plate* XVI. Allowance must always be made for the consolidation of embankments. This must vary with the character of the material and the manner in which the embankment has been made up. Embankments constructed from side cuttings in the ordinary way are generally consolidated by being trodden down during construction, and require less allowance than embankments that have been tipped. Where a high embankment is tipped on soft soil, especially that of a peaty or boggy nature, it will sometimes force up before it a huge wave of soil. In such a case the contents of the embankment will be very largely in excess of the quantities calculated from the section. In the majority of the cases it is better to allow such an embankment to find its own level, but in very bad cases it may be necessary to have recourse to fascines to make a foundation on which the bank is raised. The fascines should be in layers crossing each other at right angles. When a high embankment is tipped over a culvert, it is necessary to prevent the culvert from being overturned by unbalanced pressure. If the embankment is tipped from both ends, meeting at the culvert, one embankment will balance the other, provided that the tipped material approaches the culvert equally on both sides; but, if not, it is desirable to carry forward the earth in advance of the tip, as shown at Y, *Plate* XVI., and ram it in layers on both sides of the culvert, and, if the bank be very high, to carry out a staging so as to tip the material on the other side of the culvert until the pressure on both sides can be equalized.

In India there is a black cotton soil; it is supposed to be a disintegrated trap rock, and has an extraordinary capacity for absorbing water during the rains, and parting with it in the dry season. When wet, it assumes a pasty tenacious consistency, expanding greatly; but in the dry season it shrinks, becoming hard, readily pulverized, and developing large and deep cracks in every direction. Houses built upon it are apt to crack and become distorted, owing to the unequal expansion of that portion of the soil which is exposed to wet and that which is protected from the rain.

If the depth of black cotton soil be not too great, the best plan is to excavate down to the firm subsoil, removing the whole of the black cotton soil from the entire area to be covered, filling in the space with either gravel, sand, shingle, or other suitable material, and after consolidation, to lay a stratum of concrete; or the walls may be founded on pillars built in pits sunk to the firm subsoil and arched over from pillar to pillar, margin being left in the pit round the pillars for filling in of loose material, such as gravel, etc. If the depth of black cotton soil be too great for either of these alternatives, a shallow excavation may be filled with loose material, giving a wide margin round the building, and after consolidation the concrete base may be formed on this. Framed houses are more suitable than ordinary houses in black cotton soil.

For bridges in black cotton soil, screw piles may be used with advantage if firm subsoil is to be met with within practicable depth.

Some idea of the expansion of black cotton soil may be formed from the fact that, on a railway in South India, a permanent-way inspector reported at the commencement of the rains a serious sinkage in the foundations of a bridge, but on levelling back to a permanent bench-mark to ascertain the amount of sinkage, it was discovered that it was the embankment of black cotton soil that had expanded from the absorption of moisture, raising the permanent-way bodily with it, and thus giving the appearance of a failure in the foundations of the bridge, which were perfectly sound.

Steam navvies and excavating machines can seldom be used on railway construction, as their transport is, as a rule, too expensive, and their use too limited, to render them generally available. It is only on very large and concentrated works that they can be employed with advantage. In the United States of America, light scrapers are sometimes employed in the construction of shallow cuttings; the ground is ploughed over, and four scrapers, each with a pair of horses and drivers, work round and round in a circle without stopping, the circumference of the circle on one side reaching to the centre of the excavation, and that of the other to the part where the soil is deposited. In soft soils, this plan is very economical. For small embankments, horse-scrapers have been combined with endless bands, which carry the earth to a receptacle, and when this is filled it is removed to the site of the embankment and the earth is tipped. These horse-scrapers are only suitable for railways in prairie lands.

In some cases, when a large volume of water has been available in the cutting, it has been used to wash down the contents of the cutting into an embankment; but this is generally difficult of control, and only available in very exceptional cases, where the material is suitable and water is available.

FOUNDATIONS.

In some localities a firm soil for foundations cannot be obtained within any reasonable depth; in parts of the delta of the Ganges, for example, the soil is alluvial, and the lower excavation is carried, the worse the soil becomes, ending possibly in a quicksand, if the excavation be carried deep enough. In such cases, the best plan is to excavate shallow foundations only, and to float the structure, as it were, on a monolith of concrete in cement. The thickness of the concrete must be sufficient to prevent its fracture from unequal pressure. I have seen a high building in Calcutta, founded on a concrete bed, indicated at **A**, *Plate* XVIII., only 9 inches thick, with scarcely any margin of concrete beyond the footings; it might almost as well have been founded on brown paper. Instead of spreading the weight of the building over the whole area to be covered, the pressure was limited to the area immediately under the walls, with the result that the earth was pressed up between the walls, the building itself cracked in all directions, and another building some 30 feet distant was drawn over out of perpendicular and badly cracked. The proper mode of dealing with these foundations would have been to put in a mass of concrete over the whole area, as indicated in the dotted lines in the diagram.

Soft soil may be consolidated by enclosing the area to be built upon in sheet piling, and driving down piles at short intervals apart over the whole area, and then covering this area with a mass of concrete; sometimes to economize in timber the piles are driven a certain distance and then extracted, the holes left by their extraction being filled in with firm sand.

Sand itself forms an excellent foundation, if it cannot escape. If there is no possibility of its being under-scoured or drawn off by pumping operations, it can be safely loaded to five or six tons per square foot.

In putting in foundations it is desirable to avoid stepping up or unequal depths, which are apt to produce cracks and unequal settlement. Made-up ground also, in a foundation, is to be avoided as likely to cause failure when there are inequalities in the foundation. As a rule, the whole area should be taken down to the full depth of the lowest part where the foundation is sound; there are, of course, exceptions in which a departure from this general rule may be allowed. For instance, when building on a sandy tract, the surface may be so much broken that it may be necessary to fill up the irregularities with sand of the same character as that of the whole tract. Such a case occurred in France, where a high building was to cover a large area, and there were differences of level of 45 feet within the area to be covered by the building. These irregularities had to be filled in. It was obviously impossible to follow the contour of the ground with the foundations. The surface was, therefore, levelled, and trenches—in the made-up sand—were dug for concrete. These trenches were then well rammed and flooded with water until no more water was absorbed; the concrete was then rammed into them. This method proved perfectly successful, but, of course, it would be impracticable with any material except sand.

In pile driving, a heavy monkey with a comparatively low fall is more effective than a small one with a high fall, and it is less liable to shatter the head of the pile.

Nasmyth's steam pile-driver is very useful when a large number of piles have to be driven. The rapidity with which its blows follow one upon another enables piles to be driven with great speed.

In many cases screw piles will be found very convenient where sound foundations are at a considerable depth; the speed with which they can be screwed down renders them valuable not only for permanent use, but also for temporary work, and in cases where communication has to be rapidly restored. When no longer required for temporary purposes, they can be easily unscrewed and taken out to be used elsewhere as necessary.

A convenient size for screw piles, for railway purposes, has been found to be 30 inches outside diameter, with metal 1 inch thick in 9 feet lengths, the diameter of the screw being about 4 feet 6 inches, with a pitch of 7 inches. Such piles are screwed with a capstan head, from which arms, composed of rails, project, and ropes passing round grooves in rail ends are worked by a crab winch or capstan, and sometimes directly by eight bullocks. The weight of a pier of two piles 40 feet long, with bracing, is about 16 tons. For smaller structures, piles 18 inches diameter, with a screw of 3 feet 3 inches in diameter, worked by two double-purchase crabs, can be screwed down through marl or clay at the rate of about 8 feet per day; six men are required at each crab, four in winding and two in taking up the slack of rope which passes round the capstan bars, fixed to a disc, tightly clamped to the pile. One mode of rotating the piles is by means of a solid hexagonal shaft bolted on to the head of the pile to be screwed down. This shaft passes through the centre of the cast-iron wheel, which is sufficiently loose to allow the shaft to be sunk with the pile whilst the wheel turns. It always remains at one level throughout. The circumference of the wheel is toothed as a worm wheel, so as to gear into a worm-screw on a horizontal shaft, which is worked by handles like a common winch. Two of these worm-screws are required, one on each side of the wheel, to take the lateral pressure from the guide; the whole arrangement is supported on a solid frame.

In some cases it is found advantageous to serrate with teeth the bottom of the pile, and also its edge, to enable it to cut through obstacles that may be encountered. The screwing down is sometimes greatly expedited in hard material by clearing away from the interior of the pile the core of gravel or sand that may have accumulated within it. This may be done in various ways, either by means of a scoop, a screw augur-shaped receptacle, or a sludger, or small dredger, or by a strong jet of water forced down by a pipe. When the core is of a refractory character, and cannot be readily taken out by these means, a long piece of rail, sharpened at one end and suspended from the top, may be worked up and down like an engine to break up the core. In such a case the cylinder should be protected from injury by a species of fender of wood attached to the upper portion of the rail.

Wrought-iron solid piles are sometimes used with a cast-iron screw; they are generally about 6 inches diameter, in lengths of 20 or 25 feet, the bottom length being keyed into a cast-iron screw 3 feet 6 inches diameter, with a pitch of about 8 inches; the ends of the pile are inserted into the socket of the screw, and are reduced on both sides by two flats. The coupling of the lengths is effected by a wrought-iron sleeve 10 inches outside diameter, and about 21 inches in length, keyed on and secured by pins.

Such piles, though they answer very well for jetties or places not exposed to vibration of trains at high speed, have in some instances proved to be very unsatisfactory when used for railway bridges, especially when there has been a considerable length in water unbraced. On the Madras Railway, bridge piers constructed of such piles racked so much that most of them were taken up. Moreover, they are almost entirely dependent on their disc for support, whereas the hollow screw piles of large diameter obtain considerable support from skin friction; in fact, when screw piles of small diameter, and consequently of small skin friction, are employed, the increase in the depth to which they are screwed does not necessarily increase their supporting power; *Plate* XIX., exhibiting the failure of a screw pile bridge, furnishes a salutary lesson in this respect. The piles of this bridge showed an inclination to settle slightly, and it was decided to screw them down an additional length, but the engineer, instead of testing the stability of the piles by a dead load, assumed that the additional depth had given increased support, and sent a locomotive on to the bridge, but the screw pile had penetrated a softer stratum, and was in reality less stable than before, consequently it failed under the weight of the locomotive.

Lugs are generally cast on screw piles for the purpose of attaching the bracing. If these should happen to be broken in transport, or if it should be necessary to provide lugs at a place where they do not exist, an efficient substitute may be made by boring bolt-holes to both sides of the pile for an eye-bolt, as shown at **B**, *Plate* XVIII.

A convenient mode of bracing screw piles in such a contingency may also be made, as shown at **C**, *Plate* XVIII., by a cast-iron pipe, through which a long bolt may pass, abutting against wrought-iron lug pieces, to which the diagonal ties may be fastened either by rivets or bolts.

LECTURE III.

WELL FOUNDATIONS.

THE method of forming foundations by sinking wells has been from time immemorial in general use in India. Originally these wells were made with wooden curbs fastened together with trenails. The curb was generally laid on the bed of the river in proper position and the length of well built upon it; the first few feet were excavated by a native spade and the material hauled up by bucket; the well descending into the sand or clay as it was excavated beneath the curb. When excavation had been carried to a depth greater than that at which the material could be excavated by such means, a "jham," as it was termed, was employed. This was a tool shaped somewhat like an adze, with a rope attached to it; it was lowered into the well, and a native diver descended and pressed the "jham" into the sand, the rope was then hauled up from above, bringing with it the "jham" and such material as could be excavated; the form of the "jham" is shown at **D**, *Plate* XVIII. This plan was improved in the early days of railway construction in India by using a long pole socketed into the "jham," so as to avoid the use of a diver to press it into the material at the bottom of the well. Subsequently, when wells were sunk to a greater depth, this gave place to a "sludger," or sand pump, shown at **F**, *Plate* XVIII. It was let down to the bottom of the well and the pump bucket worked up and down like a ringing engine, causing the sand and gravel to rise in the suction pipe until it fell over into the receiver. When the receiver was full it was hauled up, the false bottom of the receiver was opened, and the contents emptied. In order to save time, a sand pump was usually furnished with two receivers, so that while one was being emptied the other was lowered with the sand pump to continue the excavation. The rate of sinking a 12-foot well with a sand pump was about 6 feet in 8 hours. The size of stones brought up in the receiver was sometimes considerable. I have myself seen a roundish boulder about 5 inches in diameter brought up by one. The sand pump in its turn gave way to a class of dredgers shown at **E**, **G**, and **H**, *Plate* XVIII. The time lost in lowering and hoisting the dredgers makes the work of excavating slow, but it is greatly accelerated by the use of efficient steam hoisting plant and large dredgers shown in the photograph.

Bull's dredger is one that has been largely used, and is very effective. It is shown at **H**, *Plate* XVIII., in the process of being lowered. As soon as it reaches the bottom a catch falls out, and enables the jaws to close on the sand, which its own weight enables it to grip, finally closing as indicated by the dotted lines.

In fine sand the dredger often comes up empty if obstacles should prevent the jaws from entirely closing, as indicated by the dotted lines in *Fig.* **H**.

I think it probable that the centrifugal pump or ejector may, in future, supersede or supplement the dredger where only light sand or mud is to be excavated; for the work of either a centrifugal pump or an ejector would be continuous. A jet of water at high pressure, combined with an ejector, would excavate and stir up the sand which the ejector would carry off, provided the ejector were kept in constant movement over the whole area at the bottom of the well.

For very stiff clay and gravel a jumper, formed of a long steel rail pointed at the end or chisel-shaped, may be lowered to the bottom of the well, then raised about 10 feet and suddenly let go, so as to indent itself deeply into the gravel. This operation may be repeated until a large portion of the clay or gravel at the bottom of the well has been disturbed, and a dredger sent down to take up the detached lumps of clay or gravel. The rail should have a fender at the upper end, to prevent injury to the sides of the well, as shown at J, *Plate* XVIII. In south India a circular box receptacle, with a cutter of helical form, has been used with some success in the excavation of stiff clay, the box being rotated by rods from the top of the well; the clay cut being forced by the rotation into the box, which, when filled, is hauled to the surface to be emptied. But excavators of the Milroy type, shown at G, *Plate* XVIII., or spiders, such as that shown at E, appear to be more generally useful. Some of these spiders are furnished with a falling weight, which is used as a monkey to drive the excavators into the hard soil. The "Fouracre spider," shown at E, *Plate* XVIII., is a convenient tool. It consists of six picks arranged round a central shaft, to which they are hinged. The sliding monkey on the shaft, worked by a rope, strikes on a boss, which transmits its blows through the rods to the picks, and drives them into the clay, causing them to close, umbrella-like, on a mass of clay. When the spider is lowered by the boss, the picks are kept open, but when hauled up by the shaft they are kept closed, as shown by the dotted lines. The spider is generally used merely to break up the clay, so as to enable it afterwards to be brought up by ordinary dredgers. The picks are generally made sharp and pointed if used for breaking up gravel, but if the clay is to be retained and brought to the surface they should be broad and flattened out. In some cases they are not only flattened out, but forked. But the proper form to be used must depend chiefly on the character of the material. The ram should not be too heavy, otherwise the picks are likely to be broken.

The outside of the well is generally plastered over to decrease the friction in sinking, and a scale showing the height above the bottom of the curb is painted on the outside of the wells.

Plumb-bobs hung outside the well should be continually watched during the process of sinking, and when any indication of canting is observed immediate steps should be taken to remedy it. Sinking should be stopped, and the causes ascertained, and, if necessary, divers sent down to clear any obstacle. Canting is sometimes caused by excavation carried unequally at one side of the well, but more frequently by the curb meeting some obstruction at one side, either from stiff clay, boulders, or sunken timber.

If canting takes place during the first three lengths sunk it may be generally remedied, but beyond this it is almost hopeless to restore a canted well. When a well has once canted it is obvious that the tendency to cant is increased by the action of the dredger, which excavates precisely where it should not, and avoids that part which requires excavation to restore the well to the perpendicular, as indicated at **N**, *Plate* XVIII. It is desirable, therefore, in designing well curbs that some arrangement should be made by which a diver can, if necessary, attach a swivel-hook of a wire rope to the curb, so as to have a guide which will force the dredge to excavate in the position desired, as shown at **P**, *Plate* XVIII. In spite of all precautions, wells will sometimes be drawn out of the perpendicular, and when this occurs a strain should be put upon the well to straighten it; this is sometimes effected by passing a chain round it, making the chain fast to some fixed point and weighting it, as shown at **K**, *Plate* XVIII. A comparatively small weight will exert a great strain on the well, and a slight vibratory movement of the weight up and down will assist the action, which, however, must not be overdone, otherwise the well will be crippled. The well should be protected with sleepers, so that the chain may not bear directly upon the brickwork. Another plan is to put a jib on the well with two spars and a topping lift, and to load the end of the jib as indicated at **L** and **M**, *Plate* XVIII. Where sunken timber is encountered in well sinking it may, sometimes, be broken up, if first weakened by boring a number of holes through it, close to the curb, by means of a long auger worked from the top of the well, the point of the auger being inserted in position by a diver; chains are then passed round the timber and it is hauled out by a powerful lifting tackle. A small dynamite cartridge exploded against the timber may help in breaking it up, but any such explosive must be used with great caution, otherwise the curb may be injured.

Although rectangular blocks have been for many years sunk in irrigation works, the well piers in the earlier years of railway construction in India were almost always composed either of single cylindrical wells, shown at 1, *Plate* XX., or groups of two or more wells, as indicated in *Figs.* 2 and 3, *Plate* XX. But of late years double hexagon and octagon well-blocks have been largely used with satisfactory results. The double octagon-block (*Fig.* 6, *Plate* XX.) is, as a rule, preferable to the double hexagon-block (*Fig.* 5), as it allows the dredger to excavate more equally near to the periphery, and reduces the tendency of the well to hang on its angles in sinking; but probably a double cylindrical block, shown at *Fig.* 4, would be more satisfactory than either in this respect.

The character of the scour around unprotected wells is indicated at *Fig.* 7, *Plate* XX. The current meeting the obstacle is deflected downwards, resulting in the scour of a conical hole around the well, the scour being deeper on the up-stream side of the well than on the down-stream face. This has been shown by the fact that in the majority of cases, when the fall of a well has been observed, it has fallen up stream.

In the Chenab Bridge, where each pier consisted of three wells, the engineer-in-chief, being pressed for time, had not carried out my instructions with regard to three of the piers before the floods set in. These instructions were to cut down to low water level every well that was not fully down, and to protect it with loose stone. When the floods came on the scour was so great that the unprotected wells fell, though sunk to a depth of nearly 70 feet on to stiff clay; the up-stream well fell the first.

Fig. 8, *Plate* XX., shows the mode in which the stone protection is applied; in some cases it is laid over in a flat ring of equal depth, but I prefer to pile it round the wells, and to allow it to find its own level as the scour takes place; more should be deposited on the up-stream than on the down-stream side, so as to allow for movement of stone in the direction of the stream, but as a general rule the travel of the stones under scour is not great. *Fig.* 9, *Plate* XX., shows how the stone adjusts itself to a scour, and protects the material underneath it from further scour until a depth is reached when the scour becomes so feeble that it ceases to undermine the loose stone. Wells, therefore, protected in this manner stand in a species of cone, composed of sand or clay, and coated with a protection of loose stones. The effects of a flood should be carefully watched, and if any subsidence is shown in the mass of stone more should be added to maintain the upper portion of the cone about low water level. The quantity of stone round each pier of the bridges in the Punjab rivers averages about 40,000 cubic feet, but in some cases where scour has been excessive, the amount has reached as much as 50,000 cubic feet. Well piers in some rivers have been sunk to depths of 75 and even 100 feet below the average bed of the river, but if properly protected with stone the necessity for sinking wells to such great depths is doubtful; 50 feet would appear to be ample, standing as the wells do in a cone protected from scour by a mass of stone.

Fig. 11, *Plate* XX., shows the section of curb generally used, but the coned plate is difficult to make and expensive, and if made as shown in *Fig.* 12 it is equally effective.

Plate XXI. shows a double octagon well curb ready for sinking, and *Plate* XXII. shows a double octagon block sunk and ready for building a fresh length upon it.

In sinking the double wells close to each other, the wells have a tendency to draw together; this was obviated to a great extent by use of three-well piers, the two outside wells being sunk sufficiently in advance of the middle well to avoid any tendency to draw into the cavity formed by the other wells, as shown in *Plate* XXIII.

If the inside well were sunk in advance of the outer wells, it is obvious that there would be a tendency in these wells to draw towards the space excavated between them. *Plate* XXIV. shows a three-well pier in course of construction, the outer wells being built up before the inner well, and *Plate* XXV. shows the two outside wells sunk in advance of the middle well.

In the bridge over the Ganges at Benares, large oval blocks somewhat of the section shown at **A**, *Plate* XX., but divided in three compartments by partition walls, were sunk without difficulty. But this form is somewhat weak, and the partitions render dredging somewhat difficult.

Where greater lateral width is required to support very large or high piers, or a double line of railway, the form as shown at **B**, *Plate* XX., or the "four-hexagon" blocks indicated at **C**, might be adopted. For purposes other than piers, such as the formation of wharf walls, where an extended line of wells might be required, a system of alternating double and single hexagon blocks, as indicated at **D**, *Plate* XX., or the double hexagon employed alternately endways and sideways, as indicated at **E**, might be adopted with advantage. The dark sections indicating the alternate blocks.

Taper wells, larger at the base than at the top, have sometimes been tried under the idea that they can be sunk more easily, and that they will afford a large area of base, combined with smaller resistance, to the current; but there is much difficulty in keeping such wells straight while sinking, and the difficulty of dredging close to the curb is greatly increased. Moreover, although the tapered form may offer less resistance in actual sinking, it must be remembered that this characteristic would really impair its supporting power when it had once been sunk. The supporting power of a well is mainly due to what is termed "its skin resistance," or the frictional resistance of its sides, and not to the area of its base, and this friction resistance would be, to a great extent, lost by the adoption of a taper pier. The pressure on the base of a well foundation cannot be calculated on the assumption that the unit of pressure is equal to the superincumbent weight divided by the area of the base. In the Hawksbury bridge, in New South Wales, the caisson is slightly tapered up to a considerable distance above the base, and the very great difficulty experienced in keeping these caissons straight is attributed to the taper given to the lower portion. On the Sind, Punjab and Delhi Railway a large number of bridges were constructed on single wells 12 feet 6 inches in diameter, carrying girders of 100 feet in the clear span. The railways ran on the top of the girders, so that the girders might be brought sufficiently near together to rest on the top of a single well. The wells were sunk 40 feet below the average depth of low water, but they were not protected from scour in any way, and a large number of them fell, the sand or clay having been scoured to such a depth that they were no longer stable. The abutments of these bridges were of an extremely expensive character; some of them consisted of 60 wells in each abutment. Upon these wells the abutment and wing walls were built on arching from well to well, as indicated in *Fig.* 12, *Plate* XXXII.; the wells varied from 9 feet to 12 feet 6 inches in diameter, and the depth to which they were sunk varied from 35 to 40 feet. Many of these abutments failed lamentably; the water in flood washed out and in between the wells, gradually removing the earth between them, and the scour which followed completely overturned a large number of the wells, together with the walls which they supported. For bridges of this character I always adopted that which I should term a pier abutment; in fact, one exactly like the other piers of the bridge, the only difference being in the protection, which consisted of a large mass of stone surrounding the pier and coating the embankment, as indicated in *Fig.* 13, *Plate* XXXII., the cost of such piers being insignificant when compared with rows of wells such as I have described, and infinitely more effective.

Well sinking requires great care, especially at the commencement of operations. The curb should be pitched with great exactness, and carefully levelled, so as to ensure that it is quite horizontal before it is built upon. It should be sunk to its own depth before building upon it at all. It is a mistake to build too great a length of masonry on the curb at first; very little pressure is required for sinking the first few feet, and, if too great a length be built upon it at the outset, it is liable to cant, and when once a well has canted it is difficult to bring it back again. A length equivalent to about half the diameter of the well is generally sufficient for the first length; this is generally sunk by hand labour, taking out the material equally all round the interior, and if any indications of canting should be observed, immediate measures should be taken to bring it back again by excavating on the higher side and weighting it. The second length may be about equal to the diameter of the well. When the second length has been sunk properly, the critical period may be said to be passed, but great care and watchfulness are required, and when any indication of tilting is observed, it should be taken in hand at once. It is not prudent to build lengths much more than one and a-half or two diameters above the ground at one time, for too much top weight will intensify any tendency to tilt, and the further a well is sunk the more difficult it becomes to remedy a cant if it should once be allowed to commence. When the site of a pier is in water of greater depth than the curb, it may be necessary to have recourse to a caisson; such a caisson is shown in *Plates* XXVI. and XXVII., which illustrate the mode of pitching it. If the surface below the bottom of the well be not quite level, it should be dredged perfectly level over the whole space on which the caisson is to be deposited. If this cannot readily be done, the caisson may be suspended and the material cleared away if it bears unevenly. Such caissons, however, are costly and expensive, and they may in many cases, when the water is not too deep, be avoided by the formation of an island, on which the curb may be placed. This may often easily be effected either by the construction of a temporary brushwood obstacle, or by driving a few rough piles in a segmental row close above the site of the proposed pier, backing up the piles with brushwood or fascines, or other contrivances, to allow the water to pass through with a diminished current, and form a sandbank by deposit. If the silting process be too slow, the formation of an island may be expedited by supplementing the obstacle with sandbags and depositing sand behind it, but it is better not to place the segmental obstacle so near as to interfere with sinking operations.

Plate XXVIII. shows the arrangement for dredging by steam hoists in the dry bed of a river. *Plates* XXIX. and XXX. show the arrangement of floating steam hoists.

It is very desirable when working in sand not to excavate too far below the curb; for if there should happen to be a difference in the level of water outside and that inside the well there may be a blow-in from one side, forming a cavity which may cause the well to travel or cant, and all the material blown in must be excavated before further sinking can be proceeded with. Moreover, if the excavation be carried too low, the well may sink with dangerous rapidity. A case of this kind occurred in sinking the oval block wells of Benares bridge; the well sunk so suddenly that it forced a violent rush of water up the interior of the well, bursting the well, and breaking away a large portion of the brickwork.

If a well sticks, emptying its water will often give it a start, and sometimes a dynamite cartridge, exploded under water at the bottom of the well, will, by its concussion, produce the desired effect.

When a well has been sunk to its full depth, it should be loaded with rails and then filled in with concrete. *Plate* XXXI. shows wells thus loaded. Some engineers, to save expense, fill only the bottom of the well with concrete, leaving an intermediate space filled with sand and gravel, on which the upper portion is concreted before the pier is built upon it; but unless the well has been sunk without difficulty, it is more prudent to incur the slightly increased expense of concreting throughout, for I have known many cases in which wells have been cracked in progress of sinking, and the fact has not been discovered until the material surrounding it has been scoured away and the portion cracked has fallen out; in such cases sand or gravel filling will be useless.

A very ingenious arrangement was devised by Sir Bradford Leslie for sinking the iron cylinders of the Gorai Bridge. This arrangement is roughly indicated at C, *Plate* XXXII. The clay or sand at the bottom of the cylinder was excavated, or rather ploughed up, by four rotating sets of cutters attached to a horizontal disc, so that, in rotating, the cutters excavated a conical hole about 9 feet in diameter. The boring head was bolted to the bottom of an annular shaft 13 inches diameter inside and 26 inches outside, the space between the inside and outside being filled with air so as to combine the resistance to torsion with buoyancy, the shaft was held in place by guides moving on four guide rails. The shaft and boring head were caused to rotate by means of a turbine, thus supplying water to the cylinder by means of two centrifugal pumps, and keeping up such a head that there was a constant discharge up the whole shaft, taking with it sand and lumps of clay that were cut by the rotating cutters. The time of revolution of the boring head was about a minute and a-half or two minutes, and the speed of sinking about four and a-half feet per day, including the time occupied in removing and re-fixing the driving gear and the syphon.

In one of the rivers in India one side of the curb of a well, when sunk to a considerable distance, rested on rock which was slightly inclined, and as the river bed above it consisted of coarse but very clean sand, I had a large quantity of cement thrown down so as to cover the bottom of the well, and after allowing it to settle down at the bottom for a short time, water was pumped in at the top of the well so as to produce a head of water inside the well greater than that in the river. This had the effect of forcing the cement through the sand on all sides at the bottom of the curb, and it was then allowed to set, forming the sand between the curb and the rock and all round the bottom into a mass of concrete or artificial stone; subsequent probing proved that the result had been entirely satisfactory, but if the sand in the river bed had been dirty or clayey, I should not have ventured on such an experiment. The distance from the curb to the rock in this case was small and fairly regular. If it had been greater, I should have preferred to have injected the liquid cement through a pipe under pressure.

In firm sand, especially when it is mixed with stone and fragments of rock, it is very difficult to drive ordinary timber piles, or to fix screw piles down to any great depth. Wooden piles cannot be driven to any depth without shattering, and screw piles, whether hollow or solid, will enter the sand freely at first, but when they have penetrated to a depth of a few feet the resistance increases to such an extent that it is impracticable to sink them further. To meet this difficulty Sir James Brunlees introduced a very simple method of sinking hollow cast-iron piles by means of a water-jet, and viaducts of 50 base of spans, each 30 feet, were constructed in a sandy estuary in Morecombe Bay on this principle. Experimental piles, sunk from 16 to 20 feet, showed that under constant vibration as to which piles might be exposed to by passing trains the sand might safely be loaded to 5 tons per square foot. The piles were hollow, 9 inches in diameter, with a disc 2 feet 6 inches diameter, giving a bearing of 4·86 square feet, capable of bearing 24 tons; each pier consisted of four piles; *Fig.* **A**, *Plate* XXXII., indicates the character of these piles.

The discs were generally put down 20 feet beneath low water; several arrangements of staging for supporting the piling engine were tried, but such was the shifting nature of the channels in the sand that no staging could be maintained for more than two or three tides. To have used timber piles would cost as much per pier as permanent piles of iron; it was, therefore, determined to employ pontoons, although at the outset much difficulty was experienced in mooring them in the tideway; but practice enabled this difficulty to be overcome, and they were ultimately managed and applied with great success. For sinking the disc piles two pontoons were used; each was fitted with a small donkey engine of about two-horse power, and with a piling machine. They were moored on the ebb of tide at the site of a pier; the pile was then put in position and lashed by the top to the side block in the piling machine, the bottom being clipped by the guiding apparatus fixed on the side of the pontoon. An aperture in the centre of the disc received the lower end of a wrought-iron pipe 2 inches in diameter, which, extending up the hollow pile, was connected by a flexible hose with the donkey engine pumps. By this arrangement the water was forced down the pipe into the sand, which, being loosened, enabled the piles to sink rapidly. It was found that the piles sank rapidly through the upper, or more recent, layers of sand, a depth of from 7 to 9 feet, but that below this depth in the more compact miry deposit the process of sinking was slow. To meet this difficulty ribs or cutters were cast on the lower surface of the disc, as shown at **B**, *Plate* XXXII., by which, when an alternating motion was given to the pile, the material was loosened, and was washed or blown away by the water. This plan was found so effective that two piles were generally put down from each pontoon during the ebb of the tide. In about half-an-hour after ceasing operations so much sand had accumulated round the pile as to steady them completely. After the first tide the sand was at its full height, and then the piles were quite stationary; the operation of sinking was much facilitated by keeping the weight of the pile hanging on the pile engine chains; without this precaution the piles sometimes sunk irregularly, and occasionally so fast as to overpower the pumps.

To consolidate the surface beneath the discs which had been disturbed in sinking the piles, each pile was ultimately driven down 2 inches by short blows from a heavy tup.

As this mode of sinking is not very common, I may perhaps with advantage give a brief account of the operations on a viaduct more than a mile in length which was constructed over a wide river, near its mouth, in Chili. The river was shallow, having a depth of only about 18 inches in the dry season, with a maximum flood of about 9 feet. The bed of the river was intersected with channels about 12 feet deep below summer level, constantly varying in position. The bed of the river consisted of coarse black sand, alternating at various depths with beds of clay and gravel, varying in thickness from a few inches to 2 feet. The velocity of the current, even in flood, did not exceed 6½ miles per hour. For this viaduct hydraulic piles were used, sunk to a depth of about 28 feet below the average level of the river. Each pier was composed of six piles divided into rows of three, the distance apart between their centres along the line of the bridge being 15 feet, the rows being 6 feet apart from centre to centre. The piles were connected by longitudinal and transverse bracing above low water level. The spans were about 80 feet in the clear. The middle piles were 15 inches in diameter outside, and 1⅝ inch in thickness, with a bottom disc 3 feet 6 inches in diameter; the outer piles 12 inches in diameter outside, and 1 inch thick, with discs 3 feet in diameter. The maximum pressure on the disc area was calculated to be about 5 tons per square foot on the middle pile, and 3¾ on the outer pile. The tested bearing power of the sand at much less depth than that to which the piles were sunk was 7·34 tons per square foot. The piles were put down with water-jets pumped through a 3-inch hose into 3-inch wrought-iron pipes running down the interior of the outside piles, and discharging about 8 inches below the disc. The amount of water delivered was about 160 gallons a minute, and was sufficient to sink two piles at a time.

Figs. 1, 2, and 3, *Plate* XXXII., show the arrangement for sinking the hydraulic piles. In order to save time and expense that would have been entailed by the use of a fixed scaffolding for each pier, the platforms from which the piles were slung into position and guided were bolted to movable trestles of the form shown in the diagram at 1, 2, and 3, *Plate* XXXII. The trestle was hinged at the apex by means of a 3-inch pipe slipped through staples. After a pier had been completed, the pipe was slipped out and the two halves were floated to the next position and erected there. The foot of the trestle soon settled in the sand which formed the bed of the river, and bore up very well against the strains which came against them. Nine trestles of this description sufficed for the whole work.

When the piles came into contact with any of the strata of hard clay or gravel they were rotated by a steam winch driving an endless rope 2½ inches in circumference, wound several times round the capstan of 8 feet diameter (*Fig.* 4, *Plate* XXXII.). The arms of the capstan were of timber, bolted to a cast-iron collar or grip made in three segments. Each of these segments had two wedge-shaped recesses, into which pieces of inch-round files were dropped (as shown at 5), and when the pull came on the capstan these pieces got jammed between the pile and the narrowing wall of the recess, serving to grip the pile very firmly. This form of grip answered very well, and seldom slipped; when the pile was very wet, a spade full of sand thrown into the recess would at once stop any slipping. The piles ran in guides on the platforms above and below the capstan, and no very great trouble was experienced in keeping them straight; in fact, less than is generally encountered in driving screw piles.

The piles being slung into position, the first step was to turn on the water-jet, and let the piles down through the superficial layer of sand without rotating them. In a short time their own weight carried them down several feet, and this served to anchor the whole system to a great extent to resist any displacement from the pull of the rope. Next, the capstan was fixed to one of the screw piles, the rope was wound round it and set in motion.

A clay stratum was generally found at the finishing depth of 27 or 28 feet. The rate of sinking varied greatly. Whilst the piles were going through the pure black sand the rate of progress was very rapid, often as much as 7 or 8 feet per hour; sometimes when the disc had reached a depth of more than 12 feet the water, being unable to get away with sufficient rapidity from under the disc, would return up the interior of the pile and overflow the top, bringing up 25 or 30 per cent. of black sand, thus making an excavation under the foot of the pile, which materially assisted its descent. The clay bands occupied the larger part of the time required for sinking, and when the clay stratum was struck, in most cases close to the finishing depth, the last 2 inches often took two or three hours to sink.

The number of accidents was very small, but a troublesome one occurred. The bolts of the second joint from the bottom of one of the 12-inch joints sheared off when very near the full depth, leaving the top part loose. The disc and bottom lengths were thus left buried beneath 10 feet of sand and 8 feet of water. The extraction of these pieces caused an immense amount of trouble. The flange of the top length was at length grasped by four steel rails provided with strong steel projecting pieces, then water-jets were applied to the upper surface of the disc to loosen the soil above it, and the rails were hauled up by four 20-ton jacks bearing upon the other piles of the pier and also on an extra pile sunk for the purpose. The upward progress was very slow, but after many slips it was eventually extracted and replaced by a sound column. The lifting force exerted was probably about 50 tons.

Where labour is cheap, as in India, and the piles to be driven not many, it may be a question whether hand labour for rotating the piles might not be cheaper than steam power, the transport of which to the site of the bridge is sometimes very expensive.

A water-jet might with advantage be combined with a screw pile, using the jet alone when sand might be encountered, and using it in combination of rotation of the screw when passing through clay or gravel. The jet would tend in such soil not only to loosen it, but also to lubricate the screw and allow it to rotate more freely. A very useful adjunct to the water-jet would be a set of adjustable nozzles of different forms and diameter, to be used under special circumstances. In some soils it might be necessary to direct a small jet under very high pressure rather than in great volume. In other cases, such as a stiff clay, the descent might possibly be expedited by an oblique or even horizontal jet (as indicated in *Figs.* 7 and 9, *Plate* XXXII.); in such case, the pipe carrying the nozzle would be rotated in a stuffing box.

With a vertical jet, where sand is mixed with stone, the stones are apt to collect under the centre of the jet, as shown at 6, *Plate* XXXII., and prevent further descent. The oblique jet, if rotated, would prevent this tendency, as the stones would naturally fall towards the lowest part, as indicated at 7, so as to clear the disc. For stiff clay, a powerful horizontal jet might be adopted, as shown at 9, the action of a vertical jet being insufficient, as indicated in *Fig.* 8, *Plate* XXXII., to clear stiff clay away from the outer edge of the disc.

The driving of wooden piles in sand may be much facilitated by a water-jet carried down on either side from the pile to a short distance below its point. Such pipes should be kept in constant movement, to prevent their being gripped by the sand, and when the piles reach their full depth the pipes are withdrawn, and can be used in sinking other piles. With such an arrangement, timber piles can be driven with a comparatively light monkey, and it has been found that timber piles so driven could be sunk with about 50 blows of the monkey, whereas without such an arrangement it required nearly 200 blows.

Pott's vacuum system for sinking cylinders was first applied to a bridge on the Chester and Holyhead Railway. The cylinders were 12 inches in diameter, and were sunk by means of a double air-pump sinking as the exhausting process was continued. Afterwards tubes of 6 or 7 feet in diameter were tried, but the simply exhausting process was insufficient to overcome the friction of the sides, and a supplementary receiver was employed, from which the air was exhausted, and when the exhausting process had proceeded as far as practicable, communication was suddenly opened between the receiver and the cylinder, producing a double effect, the shock by the sudden rush of air, combined with a blow on the head of the pile, was frequently successful in starting it when other means failed. The attempt to sink cylinders 10 feet in diameter for the Shannon Bridge by Pott's system failed, and the sytem was altogether attended with such difficulties that it was superseded by the Plenum system, in which compressed air is used to drive out the water, ingress and egress of workmen, to and from the inside of the cylinder, being effected by means of air-locks. The air-lock shown at 11, *Plate* XXXII., consists of two chambers, one of which is always in communication with the cylinder, and in which the pressure of the air is always the same as that in the cylinder. The outer chamber is generally capable of containing three or four men, and has two doors, the inner door communicating with the inner chamber, and the outer door in communication with the open air. When any person desires to enter the cylinder, he can enter the outer chamber, if it be in equilibrium with the outer air; then, by closing the outer door, and opening a cock, he can establish an equilibrium of the air pressure between the outer and the inner chamber, which can then be entered. *Fig.* 11, *Plate* XXXII., indicates the general features of the arrangement. The skip, in which materials are raised, can then be taken into the outer chamber, the door closed, and an equilibrium established between the outer chamber and the outside air, so as to enable the outer door to open and the skip to be emptied out. The doors open inwardly, so that the pressure of the air tends to keep them closed, and a dove-tailed groove countersunk, in which indiarubber is inserted, forms an air-tight joint. In some cases a shoot is provided for the products of excavation, and this shoot is also air-locked; but the door at the bottom of the shoot opens outwardly, and is kept closed by a screw. In some cases the hoisting power of the skip is outside, and the hoisting rod passes through an air-tight stuffing box. In large operations, it is desirable to have a double lock, as indicated at 10, *Plate* XXXII., so that one compartment may be in communication with the exterior, whilst the other communicates with the interior. This is simply arranged by an air-lock in annular form divided into two chambers, each of which has a separate pair of doors communicating with the outside air and with the cylinder. The hinges are arranged so that the doors are free to be forced tight by the pressure of the air; the air-lock is fitted up with a pulley for hoisting the skips, and a small crane for handling them, and is well lighted with bulls-eyes. In some very large works the air-lock is of such large dimensions that it contains the entire volume excavated by the working party, so that it will only be required to be emptied at the end of each shift. This not only expedites work, but it saves the workmen from the injurious action of frequent changes of pressure. The working in compressed air is, however, objectionable, and should be avoided, if practicable, by the system of open well sinking and dredging, and is far more expeditious and economical, the cost of foundations by compressed air being 50 or 60 per cent. greater than that of open well foundation. Working in compressed air is very trying for the workmen; at depths of 60 or 70 feet it is possible for the men to work long shifts without prejudice to health, but at the St. Louis Bridge, where there was a head of water more than 100 feet, there was great mortality amongst the workmen. Out of 350 men employed in the central pier, 30 were seriously injured and 12 died. In the next pier, the conditions were better understood.

In Jutland, several men were killed by the pressure of air at a depth of 110 feet, and one of the cylinders burst, killing three men.

At the foundations of the St. Louis Bridge, over the Mississippi, a large wrought-iron caisson, or air chamber, nearly hexagonal in plan, was lowered to the bed of the river; iron plates were then added to it, so as to bring it well above water level. The water was then pumped out, and the building of the masonry commenced at the top of the air chamber. As the masonry progressed, and the excavation was carried on in the air chamber, the caisson was sunk into the sand, pressed down by its own weight. The general operation of the plan is shown in *Plate* XXXIII. A well through the centre of the masonry, provided with steps and a lift, enabled the men to gain access to the air chamber by means of air-locks; all irregularities between the rock and sand were filled in with concrete. The sand at the bottom was stirred up by powerful jets of water, and ejected by sand pumps. Anything that could not be ejected by these means was cut up and hoisted up piecemeal through smaller shafts provided with an air-lock; there were six of these small shafts. Men were only allowed to work two shifts of 45 minutes in a day. A lift was provided to save the men from ascending the staircase, and it was made compulsory for the workmen to use the lift on leaving the caisson. The men were made to lie down in the hospital boat for a short time, and were given small doses of stimulants before they departed to their homes. *Plate* XXXIV. shows the arrangement of caissons at the Forth Bridge.

On one occasion I had to found the pier of the bridge of two spans of 150 feet near the mouth of the river; the bottom was of rock, very irregular in form, varying in depth from 12 to 16 feet, the tidal rise being only about 2 feet. To prepare such foundations to receive the masonry by removing the rock would have been a very expensive operation. I decided, therefore, on making an island by the deposit of a large mass of broken stone from barges until it had reached high water level. A portion of the stone was then removed to the depth of low water level in such a way to form a pit for the reception of the concrete, leaving a stone wall or margin around it. The interstices in the bottom of the pit were then filled with stone broken small, then sea sand was washed into the interstices which still remained. The whole surface at the bottom of the pit was then consolidated by blows from a heavy monkey on the pile engine, and the pit was filled with concrete in cement, on which the masonry was built; this foundation was made at a comparatively low cost, and was entirely satisfactory.

LECTURE IV.

TUNNELS.

Tunnels should always be made on such a gradient as will allow perfect drainage of the water percolating into them. If the tunnel is a summit tunnel the gradient will probably fall from the centre in both directions, but if it should be on a steep gradient this cannot always be managed, and in that case if the percolation of water is considerable, it becomes difficult to drive the heading from the upper end. When tunnelling operations are to be carried out, an adaptation of appliances generally used in mining for minerals will, as a rule, be found the most rapid and economical manner for executing tunnel work. The appliances in mining are the outcome of years, I may say of generations, in the work of excavating, removing rocks and earths of all kinds, and some of our best engineers, in the early days of railways, gained their experience in collieries and other mines. Of late years improvements in machinery and manufacture, and the great magnitude of modern tunnels, have created appliances special to their kind.

Centreings for tunnels should generally be designed either as queen-post trussed or else so arranged so that a clear view may be obtained through their centre for the purpose of setting out. Iron centreings and strutting have, of late years, been much used for tunnelling, and have much to recommend them ; their great strength and diminished bulk, the facilities they afford for taking down, slacking off and putting on pressure, render them very convenient in many ways. When a tunnel is straight, and the setting out is done from both ends, the matter is simple ; but when the setting out has to be done from shafts, it can only be done, in the first instance, from wires arranged in an absolutely correct line at the top of the shaft. To the end of these wires are suspended heavy weights, either in water or even more viscid material, such as heavy oils, to prevent oscillation or vibration. The direction of these wires in a long tunnel is primarily determined by a powerful transit instrument ; it is evident that the greatest care must be observed in determining the direction by such means, for the length of base line at the bottom of the shaft is limited by the diameter of the shaft, and any slight error may prove to be very serious when the line thus set out has to meet another which has been run from the next shaft. The setting out should be checked over and over again, each time independently, until a good long base line has been established. It is not prudent to depend upon points that have been fixed by a transit instrument if they are on or adjacent to the top of a shaft, as the sinking operation, in disturbing the earth below, might affect the relative position of such points, and a very minute alteration in their position would be serious. When tunnels are not on a straight line, the difficulty is greatly increased, and great care is necessary in determining the length of tangents. The centre line must be very carefully laid out on the surface of the ground, especially if it be precipitous and irregular. In some cases chaining is not sufficiently accurate, the measurements must be taken by rod and plumbed. The longest tunnel on the Ceylon Railway enters with a sharp curve of 660 feet radius, then there is a short portion of straight line, and another curve of 660 feet radius running in a reverse direction, the whole tunnel being on an inclination of 1 in 45. It had to be set out from both sides, and the greatest care had to be exercised ; the centre line was set out many times in succession, each time independently of any former operation. The check was so satisfactory that the headings met exactly in the middle.

There are several systems of working tunnels, each of which have their advantage under different conditions. Sometimes tunnels are commenced under one system and changed to another as the conditions may be found to vary. Tunnels in moderately hard sandstone give the least trouble, and the construction of tunnels, even in hard rock free from shakes, is a simple question of drilling and blasting. Tunnels through shaken rock or water-bearing strata are very troublesome, but the greatest difficulty is experienced in driving tunnels through clay which expands on exposure to air.

In short tunnels of hard rock, which require no lining, the most convenient system of driving the heading is at the top. This allows the work of completion to follow up the heading rapidly by the concentration of a large number of drillers on ledges or steps, each step clearing a face for the next set, as indicated in diagram at **A**, *Plate* XXXV. It is advantageous to get the heading through as soon as possible for the purpose of ventilation. The heading should be on the centre line, for convenience of setting out. It should be about 6 feet square in section if not worked by machine; but for machine work a heading about 8 or 9 feet square is more convenient, so that the machine drills may be worked on a machine-carriage. For clay or water-bearing strata the English system of working, indicated in *Figs.* **B** and **C**, *Plate* XXXV., is, as a rule, the best for rapidity and economy of construction, and it is safer in plastic soil; it has the advantage of free space for working and ventilation; the materials excavated are easily removed, the timber withdrawn, and there is less interference with the masons than in other systems. It has been greatly used on the Continent and in America, and in some cases tunnels commenced on other systems have been completed on the English system. The roof is supported by top bars of timber, whilst a lower core is taken out, leaving a clear space of 12 or 14 feet in length for the centreing and for masons to build the lining. The top bars are drawn back from time to time as the masonry progresses.

The Belgian system (*Fig.* 3, *Plate* XXXV.) has the advantage of affording speedy and secure protection for the roof in quicksand and shaky rock, but it involves under-pinning the masonry, which, in some cases, is a very difficult matter. In the Belgian system the central core is sometimes left in while the side walls are being completed, and sometimes taken out as soon as the roof is secured.

The German system (*Fig.* 1, *Plate* XXXV.) is carried out by running two headings, one at each side of the tunnel, leaving a core in the middle. The side walls are first built, then the upper portion of the core is cleared away and the roof supported, as shown in the diagram whilst the crown of the arch is being built; afterwards the central core is cleared out. The advantage of the German system is that in hard ground it gives cheap working, the core being easily removed, having several faces, and it also avoids temporary support, thus saving timber; but in soft ground the core does not afford a reliable support, and the system involves crowding, difficulty of removing broken timber, and bad ventilation.

The iron system (*Fig.* 2, *Plate* XXXV.) has a cast-iron centreing, built up of short segments bolted together, on which the lagging rests, while segmental frames support the roofs and sides. The frames are separate and bolted to the centreing in such a way that they can easily be detached one by one as the masonry is being carried up, so as to leave only a short space unprotected between the frames and the masonry, and this space may be minimized, if necessary, by iron plates kept up by struts adjustable by screws. About eight of these centreings are required for each face; that which is furthest from the face being brought forward as the masonry is completed above it.

The mode of deep tunnelling adopted by the South London Railway deserves a passing notice, though it can only be adopted in special cases, such as cities, and can scarcely come under the category of ordinary railway construction.

The tunnel is circular in section, and is made up of short cast-iron segments with internal flanges. A shield, with a cutting edge slightly larger than the outer diameter of the tunnel, and forming a short sleeve outside it, is forced forward by hydraulic rams, the clay behind it being cleared away through an aperture in the shield. As the shield progresses, fresh lengths of segments are added to the tunnel within the sleeve; the clearance space of the shield, about an inch round the tunnel, is then grouted with cement, forced under pressure through holes in the segmental plates which form the periphery of the tunnel.

In working a tunnel in rock it is a mistake to blow out lumps so large that they cannot be easily handled, and require to be broken up, possibly with fresh holes drilled in them, before the face can be cleared sufficient to commence operations in drilling. The *débris* should be of such a character that the working face may be quickly cleared to enable the drillers to resume work with as little delay as possible after shots have been fired; moreover, large shots are apt to shake the rock and may bring away more than required, or render the roof of the tunnel unsafe for working. It economizes time if iron plates are laid down on the floor in front of the face so that when the shots are fired the bulk of the *débris* will fall upon them; then, after the larger lumps have been cleared away, the surface of these plates will guide the points of the shovel and thus enable the small *débris* to be loaded up expeditiously.

The running out of the spoil requires careful consideration, and should be as simple as possible. I have seen most elaborate and ingenious arrangements made, which have been practically unworkable in consequence of their complex nature, and were constantly getting out of order, when the ordinary temporary shift rails would have served every purpose and have been infinitely better.

Another point worthy of notice is the necessity for draining the ground above the face of tunnels, which not unfrequently start from the bottom of a gulley or ravine, so that the drainage of the hill-side tends to collect behind the face wall, and cause serious inconvenience and even danger. Such drainage should be diverted by means of cross drains to lead it into the side drains of the approach cutting, at a point some distance from the face of the tunnel, and, if practicable, to divert it altogether from the railway.

In first opening a tunnel in sound ground or rock, the approach will generally be taken out of the face, and then the top heading commenced without waiting for the cutting to be bottomed out to formation level, thus saving time in making commencement. In some cases a portable staging, as shown at *Fig.* D, *Plate* XXXV., may be employed to facilitate the tipping of the material into ordinary waggons from small working trucks, by which the heading is worked. Care should be taken that the shoots are inclined at such an angle that the waggons may not be injured by the *débris* tipped into them.

In tunnels where there is no necessity for shoring and strutting, it may be convenient to mount the centreings on a staging carried on wheels and travelling on rails (*Figs.* E and F, *Plate* XXXV.), so that it may be brought into position and then jacked up about a foot to the proper level and supported on wedges. When the brickwork lining has been completed, the wedges are slackened, and the whole staging again lowered on to the rails and pushed forward to be ready for the next length of arching. It may appear that the lift of a foot is an unnecessary height to allow for clearance, but there is sometimes not much to spare in the arches and near the springing of the arch, and the centreings should be lagged not too low down, otherwise they cannot be eased. Wedges may be put in between the centreing and the arch if there should be any tendency to movement. Care should be taken to pack thoroughly all spaces above the arch and behind the side walls. When there is much blasting to be done, the staging and centreings cannot be kept close up to the work, but when the tunnel is of material that may be got out with the pick, the staging may follow very close upon the completed section, and may be used as a tipping stage. The centreings should be "queen post," to allow small tip-waggons to run through them.

Labour may be economized in driving a heading through hard rock by a judicious selection of the position and direction for the holes for blasting, and the order in which they are fired. The object to be aimed at with the first shots is to clear out one portion of the face, which will leave the remainder less rock-bound for the succeeding shots. This may be effected, as shown at 4, *Plate* XXXV., either by a central set of holes, which are first fired to clear out the central cavity, and this is followed up by shots all round; or it may be done, as shown at 5, *Plate* XXXV., by holes drilled in such a way as to undercut the face, the holes marked by the deep black being fired as a first volley, those not deeply shaded as a second, and those not shaded at all as a third volley. If fired by electricity, or even by quick fuse, arrangements can easily be made to fire the shots in each volley simultaneously. It is not prudent to load more holes than can be fired at one volley.

Stray points projecting beyond the line of standard dimensions in finishing up a tunnel may be removed without drilling by attaching a dynamite cartridge loosely to the projection and firing it.

Two great difficulties experienced in tunnelling are want of light and air. Light can be thrown into a straight tunnel for some distance by reflecting the sunlight from an ordinary mirror on to a screen, in order to diffuse the light, but the prevalence of powder smoke in the tunnel prevents to a great extent the use of such a mode of lighting. Oil lamps of the usual torch fashion are extremely wasteful, and make an appreciable item in the cost, besides which, they vitiate the air. It is probable that electrical rock drills will come into larger use than at present, and, if so, the electric light can be produced by the electricity provided for the drills. The use of compressed air is, however, valuable in supplying fresh air to the workings. The best mode of ventilation is to push through with the heading as rapidly as possible, and when the tunnel is on an incline it will produce regular draught through the tunnel. When this is insufficient, ventilation may be effected by bratticing either by employing a furnace with a chimney to create a draught, or the air may be forced through a tube by valved air bells working in water. An ordinary fan blast may be used where the length of the tunnel is not very great. In temperate climates the want of ventilation is not so severely felt as in the tropics, where the temperature of a tunnel may occasionally rise to 120° or 130°, rendering it almost impossible to work.

When compressed air is used, the atmosphere of the tunnel may be cleared rapidly of smoke immediately after firing the shots by using a sprayer or nozzle, by which the compressed air can draw water and convert it into spray, which, if directed to all parts of the tunnel near the working face, will rapidly beat down smoke.

In first opening a tunnel, the approach is generally gulleted to the face, and then the heading is commenced. It is a great mistake to endeavour to reduce the length of the tunnel at the expense of too deep a cutting in the approach, especially if the cutting be in material liable to slip, or be in shaken rock. The economic depth at which the cutting should end and the tunnel commence, of course, varies with the special condition of each case; the cost per unit length of tunnel has to be weighed against that of cutting to determine the point. Roughly speaking, it is generally between 40 and 50 feet. But if on opening out the approaches there be any chance of slips, it is prudent to stop short at the economic depth of cutting and begin the tunnel. Should any slip be developed where the cutting is very deep, progress should at once be stopped, and a length of masonry should be put in and covered up with earthwork as soon as possible before breaking ground for the heading.

In the course of one of my inspections I found the heading of the tunnel started from an approach in shaken rock that had been excavated to a depth that appeared to me so dangerous, considering the character of the rock, that I ordered the engineer in charge of the tunnel to secure it at once in the manner indicated above. But, before he could carry out the order, a large slip, or succession of slips, blocked the mouth of the heading, and it was weeks before the heading could be re-opened, and then only at a great expense under a shield built of timber and covered with earth. When a tendency to slip is unexpectedly developed, it may be necessary to construct in the gullet a temporary covering of timber, filling it over with earth, as shown at Q, *Plate* XXXVI. The heading must be then driven to a safe distance from the approach, and after putting in a few lengths of tunnel lining in masonry to act as the base of operation, then to proceed to work outwards, as shown at **P** and **S**, *Plate* XXXVI., through the space that has been covered over as if it were undisturbed ground, taking all the precautions necessary in ordinary tunnelling through difficult soil.

Shafts are used either to shorten the time at completion by attacking the tunnel at a number of faces simultaneously, or to save a long lead of the spoil. The distance of shafts apart must vary in the proportion of the depth and the cost of sinking them. Shafts are sometimes also sunk for purposes of ventilation; they should be from 6 to 9 feet in diameter in the clear. Horse or bullock gins, where labour is cheap and fuel expensive, will probably be more economical for working the shafts than steam hoists. When shafts are left in permanently for purposes of ventilation, the junction with the tunnel lining is often made with a cast-iron curb, but in some cases with hard bricks, as indicated in *Figs.* **F** and **G**, *Plate* XXXVI. At the junction of the shaft with the tunnel the lining of both the shaft and tunnel should be increased in thickness.

A tunnel may be unlined, as at **A**, *Plate* XXXVI., when it is in sound rock; or quarter-lined, as at **B**; or half-lined, as at **C**, by turning an arch to prevent loose or shaky bits of rock in the roof from being detached or disintegrated; or three-quarter lined, as at **D**, when the sides require support; or fully lined, as at **E**, with an invert under the railway when the material is soft or wet, or subject to heavy pressure from expansion. Tunnels are generally of false elliptical section, with curved sides of flatter radius changing into a curve of sharper radius at the top. They are generally made more lofty than is necessary, to clear the standard dimensions, as well as to allow for ventilation; and where difficult soil has to be met with it is well to allow a considerable margin in all directions beyond the standard dimensions to provide against contingencies. Where the tunnel does not give much margin, sheltered recesses should be left at frequent intervals for workmen to avoid passing trains, and at less frequent intervals recesses of a larger character should be made for stowing away tools, plant, and materials. In some soils, such as clay, which expands on exposure to the air, a circular form should be adopted as best suited to resist pressure in all directions. As an extreme case of pressure, I may mention that in a tunnel on one of the Italian railways about two-thirds of the cubic contents of the tunnel were occupied by strong oak strutting and shoring, but even then the pressure crushed the timber so that it could not be used a second time in the same tunnel. The masonry lining, 4 feet in thickness, closed in so much that the trains could not pass, and although in some places it was possible to cut away the masonry sufficiently to obtain the desired dimensions, in others it was necessary to rebuild the arch entirely, and eventually of a section almost circular.

In a tunnel in the London clay, under the Crystal Palace, the section was originally a false ellipse, in the form indicated at L, *Plate* XXXVI., but it was forced in; the dotted lines show the position which the inner line of the tunnel assumed under the pressure of the clay, and strong timbers placed across the tunnel to resist the bulging were crushed. The expansion of the clay does not take place immediately on exposure to the air; it is necessary, therefore, to open out lengths as short as possible and to use the utmost expedition in getting in the masonry and covering up the clay. *Figs.* H, J, and K, *Plate* XXXVI., show the section of the tunnel finally adopted, and the mode of procedure in working. A crown heading, as small as practicable for convenient working, is driven into the length to be taken out. The crown bars are then drawn forward and covered with polling boards, one end of each bar resting on the masonry, which is still supported by the centres; the other end is supported temporarily on props. In some cases the crown bars cannot be drawn forward, but are bricked in and fresh bars substituted for them. The crown bars are generally round timber, varying in diameter from 10 to 18 inches, according to their position and the character of the material; they are generally spaced about 2 feet 6 inches apart from centre to centre, with greater distances at the sides. They are kept apart by struts of about 4 inches diameter; the props vary from 6 to 10 inches in diameter; spaces are sometimes left between the polling boards to relieve the pressure of the expanding clay, but in water-bearing sand close polling is necessary. As the excavation proceeds, the bars are drawn forward in succession, supporting them with temporary props until a height of 8 or 10 feet of the upper portion has been excavated. A sill is then inserted and the bars supported by props resting upon it so as to release the temporary props; the sills are held in place by strong raking timbers, as well as stretchers abutting against the finished masonry. As the excavation is carried lower and lower, raking back props are inserted and supported in a similar manner. The number and strength of the rakers and props must vary according to the character of the clay. As soon as the excavation is ready, no time is to be lost in relieving the timber from pressure; the invert is first laid on the clay shaped by templates to receive it, and the sides carried up as expeditiously as possible, every arrangement being made beforehand to fix the centres and commence turning the arch as soon as the masonry sides reach springing level. The best mode of supporting the centres is on longitudinal timbers resting on a shelf corbelled out on the brickwork of the lining, as shown in the diagram at K, *Plate* XXXVI. The centres are generally four to the length, those in the middle being about 2 feet apart from centre to centre, so as to enable the bricklayer to reach over and work between the two inner centres; the leading centre is stronger than the others. In tunnels of this kind only the very best and hardest bricks should be used, either compressed machine-made, or Staffordshire blue brick, or others suitable for the purpose.

In short tunnels through rock, hand labour would probably be less expensive than machinery, especially where labour is cheap; but where the tunnel is long enough to make it worth while to bring up machinery, and the material is very hard, it would be found that the saving in time will compensate even for a higher rate in cost of working. As a matter of fact, taking all the expenses into consideration, there is not much difference between hand and machine tunnelling in cost where labour is cheap. In Europe and the United States, where labour is expensive, machine tunnelling is generally more economical as well as more rapid. It is advantageous to use water power when it is available; a small quantity with a high head will give out great power on a tangent wheel, or the Girard turbine, or other suitable motor. The water after use in the motor is also useful for cooling the air in places, and it may be worth while to bring water from some distance when a long tunnel has to be driven.

The difficulty in tunnelling, as well as in mining, is the small number of men that can work on one face, limited by the size of the face and the number of the faces. The use of powerful explosives and machine drills has greatly diminished the time in which tunnels can be driven.

In the Mont Cenis tunnel the heading was 10 feet square, and the rock drills worked with compressed air; the drills were carried on a strong iron frame moved forward on rails. The number of drills that could be conveniently used was about 11 or 12. The drills could work in any direction, but practically it was found economical to drill the holes nearly horizontal, so that one machine might not interfere with the other. The frame carrying the drills was provided with an engine worked also by compressed air for advancing or withdrawing it from the working face; the holes were bored so that the rock could be brought away in small pieces, in order to save labour and time in removing the *débris* after each blast. The relative position of the heading in the tunnel section is shown at **M**, *Plate* XXXVI., the position of the holes is shown at **N**; the holes were of 1½ inch diameter, and from 2 feet 6 inches to 3 feet deep, and four large holes 3 inches diameter were bored to the same depth as the other holes, to ease the rock and increase the effect of the blast, but these were not charged. The holes shown in black were exploded first of all to make a central cavity, those shaded lighter were next exploded, and those that are not shaded were exploded last of all. On the average the rock drills worked from 6 to 8 hours, then 1½ to 2 hours were occupied in charging and firing, and 3 to 5 hours in moving the products of the explosion. The rock drills made about 250 strokes to the minute, and four machines were kept in reserve for every machine working, to allow for repairs and renewals. The rate of boring was about 3 inches per minute in syenite and hard limestone, 8 inches in grey sandstone, and 11½ in gypsum.

In the St. Gothard tunnel, through granitic gneiss, the headings were 8 feet 3 inches square, or 67 square feet. For hard rock about 25 holes were bored from 24 to 28 inches apart, five in a row, except three holes in the centre, which were 16 inches apart on the face, converging until 4 inches apart at the bottom of the holes; all the holes were bored horizontally. The best depth for dynamite was found to be about 4 feet. Holes were made successively smaller, beginning at 1⅞ inch to 1⅝ inch, 1½ inch and 1¼ inch. The cartridges were an inch in diameter. The frame, carrying six drills, was blocked up about 5 feet from the face. The perforation required about 2½ to 3 hours. When the last holes had been driven, the frame was withdrawn about 90 yards and a waggon placed before it to receive the fragments. The first explosion blew out a conical cavity, which increased the effect of the other shots around it. The remaining holes were then charged with each about 1lb. of dynamite. The lower row remained until the others had been fired simultaneously, and then were exploded. The quantity of rock blown out at each shift was about 8¼ cubic yards. When the rock was rotten fewer holes were bored. The spoil was removed by a compressed air locomotive. The tunnel was ventilated by two sheet-iron air valves, 16 feet diameter and 5 feet stroke, connected to the end of an oscillating beam and working in water, making two oscillations per minute, and discharging about 16,000 cubic feet per minute, the air being drawn from the interior of the tunnel by a tube 4 feet 10 inches diameter placed close to the soffit of the arch. This tunnel, 9¼ miles in length, required nine years for its completion.

For the conversion of a narrow-gauge tunnel into a tunnel of broader gauge, or for the conversion of a single-line tunnel into a double-line tunnel, if room permits, the masonry of the existing tunnel may be left in, and the trains may continue to run regularly during the period of conversion. This arrangement is indicated at R, *Plate* XXXVI.; top headings being driven for a short distance at the proper level above the existing tunnel, the crown of the tunnel being kept sufficiently high to allow mining operations to proceed without interference with the original tunnel. If the tunnel is to be attacked at several points, small openings may be broken through the crown of the existing tunnel at such points and the headings driven from faces established on each side of it, the material being thrown down through openings into the waggons inside the tunnel. When practicable, shafts are preferable, as affording better ventilation.

Operations in such a case, however, must necessarily be very cramped, and it may be questionable whether it be not preferable to construct an entirely independent tunnel alongside the existing one, although in some cases there may be objection based on the disturbance of the ground, and possible injury to the existing tunnel. Independent tunnels, if made, should at all events be of a safe distance from existing tunnels, especially through anything approaching the nature of a quicksand, where pumping operations may draw off the material, producing cavities.

LECTURE V.

RIVERS.

In the preliminary examination of a country there is a tendency to under-estimate the small waterways, as much water that passes almost unnoticed through grass and scrub in flat districts is concentrated by the construction of railway embankments, and forced to pass through defined channels; whilst, on the other hand, there is a tendency to over-estimate those of large rivers, especially in alluvial districts, where shallow channels traverse the river bed in irregular sinuosities, and these are forced into deep channels when concentrated by the construction of a bridge. Information given by villagers of the height of floods is generally very contradictory and often unreliable, but the construction of a railway generally tends, by concentration, to raise the water-level above the highest flood on record. It is, therefore, desirable to give a good margin of headway. *Plates* XXXVII. and XXXVIII. show the result of insufficient headway.

In some cases, where the bed of a river is dry for several seasons, it is difficult to distinguish the bed from the surrounding country. I remember one case in which the engineer reconnoitring, actually passed through a bed of a river without being aware of it. The bed was cultivated, yet in very rainy seasons it was nearly a mile in width. As the river was one that was very seldom in flood, I decided to cross it with a causeway until some definite experience could be obtained after the embankments had been thrown up.

The maximum flood discharge of a river must often be a matter of great uncertainty, and it is very difficult to determine the maximum amount of water that has to be passed through at a given period. The method that naturally suggests itself is to ascertain the drainage area and the maximum rainfall from such records as may exist, and calculate the total quantity, making due allowance for absorption. Several formulæ, based on the experience of large rivers, are more or less useful for the individual districts on which they have been based, but it is evident that such formulæ must be used with great caution, for no two localities present the same conditions. I may cite two cases, of entirely different character, to show how little dependence can be placed on co-efficients depending on a given catchment area or length of main drainage. At Cherra Pūnji the annual rainfall is somewhere from about 600 to 800 inches, yet at Shillong, only 30 miles distant, the rainfall is barely over 100 inches. The moisture-laden clouds, coming straight over from the Bay of Bengal, pass over the moist warm country of Lower Assam, and suddenly meet a precipitous ascent several thousand feet in height, and comparatively cold, in consequence of the great elevation. The result is a sudden condensation of the vapour, giving an enormous rainfall, but by the time the clouds have reached Shillong they have parted with much of their moisture.

The other case is that of the Guggur river, which has its origin in the Himalaya mountains. In the rains it is a broad but somewhat shallow river about half a mile in breadth, with a current so swift that it can scarcely be stemmed by an elephant in floods; yet this river decreases as it recedes from the mountains, and at last loses itself in the desert, and never reaches the sea.

In my first lecture I stated that in some cases it might be possible to supplement a bridge by an arrangement in which the surplus water of an excessive flood might pass without injury over a low causeway, or portion of the line specially protected.

Such an arrangement is roughly indicated in diagrams **A** and **B**, *Plate* XXXIX., where the surface is protected with loose stones, and the water allowed to pass under the rails and between specially designed cast-iron sleepers; the railway at that part being a surface line.

The rivers of India present very difficult engineering problems. Their vast size, their formidable power of erosion, their silt-bearing capacity, and their habit of wandering, render them very difficult of management. Frequently they occupy the highest ground, as indicated in diagram at **C**, *Plate* XXXIX., for in flood-time, when they spill beyond their natural banks, as soon as comparatively still water is reached, being super-saturated with silt, a deposit takes place, and the further the spill travels from the main channel the less silt there is to deposit. In such cases the bed of the river is much wider than is necessary for the actual amount of water, and the deep channels wander from side to side of the bed in undulations, each undulation moving successively forward, as indicated by the lines 1, 2, 3 in diagram **D**, *Plate* XXXIX. In time the bed of the river gradually rises by constant deposit, and at length some of these undulations burst through the natural bank and may wander miles away. The Indus river is a case in point; the small sketch map at **E**, *Plate* XXXIX., represents the river with some of its old beds. Jacobabad is about 40 feet below the level of the Indus at the spill, and a few years ago was in some danger of being washed away. Formerly the river must have had its mouth in the Run of Cutch, about 100 miles away from its present mouth. At another time it flowed round by the Muncher Lake, and it is quite within the bounds of possibility that it may, at some future time, abandon the Sukkar channel—over which an expensive bridge has been constructed—and resume its old course by the Muncher lake. These difficulties are enhanced by the fact that many of the valleys in the Himalaya Mountains are liable to enormous slips, which form temporary lakes of enormous magnitude, and when these burst they give rise to terrible floods. Many years ago one of these caused a flood of 90 feet above the ordinary level, at the point where we have bridged it at Attok. There is, therefore, danger in giving too little waterway in such cases.

As an illustration of the character of some of these rivers, I may mention that the engineer in charge of a large bridge over the Sutlej river reported the existence of huge floating sandbanks in the river, which moved several hundred feet in the course of 24 hours, and he proceeded to account for their existence on the supposition that a mass of jungle and bamboos had accumulated in the river and become covered with sand. A study of the sketch, shown at F, *Plate* XXXIX., sent up by the engineer, convinced me, however, that they were not floating, but were simple sandbanks, the noses of which were constantly cut away by the current, which, being already saturated with silt, immediately deposited a corresponding quantity of silt in the still water in the rear of the sandbanks, and I suggested that the engineer should put a flag on the sandbank and take observations to it from time to time with a theodolite, to ascertain whether the movement was real or only apparent, with the result I anticipated. The silt-bearing and erosive character of these rivers is enormous. I have known instances of a sandbank having been formed where, 24 hours previously, there had been a channel 20 or 30 feet deep.

One river near Peshawar lies so high above the adjoining country that I found it necessary to run up to it with a gradient of 1 in 100 for about a mile. The river was then crossed by four spans of about 40 feet each, and then the line descended at once with a gradient of 1 in 100 for about a mile.

The Kūsi river, which takes its rise in the Himalayas, has a straggling bed of about seven miles in width.

In districts near the foot of the hills there is generally a substratum of boulders at no great depth below the bed of the river, but as the distance from the mountains increases, the soil is alluvial to an immense depth.

At the junction of the Brahamputra with the Ganges, the Goalundo station, the terminus of the Eastern Bengal Railway, was threatened by destruction from the erosion of the river bank. At large stone groyne was thrown out to protect the station. The work was one of such magnitude that a committee, of which I was a member, was appointed to consider whether further expenditure on such a work was desirable. I was strongly opposed to the continuation of the work on the ground that the expense of any work sufficient to counteract the combined effects of two such mighty rivers must be practically prohibitive; but the other members of the committee were opposed to this view, and I could only record my dissent. The groyne, a huge mass of loose stone, brought down in barges from a considerable distance, stood well, but the river rapidly eroded its banks in flood, sometimes cutting away several hundred feet in the course of a few days in the manner indicated by the dotted lines at G, *Plate* XXXIX., until it cut a channel behind the spur, which then hastened the destruction of the station by intensifying the current between itself and the shore.

The original position of the groyne or spur is roughly indicated at H, *Plate* XXXIX., but on my last visit to the spot the two rivers were cutting towards each other, as indicated at J, and a curious problem as to the future direction of the river presented itself. If the erosion should continue, and, at the time of meeting, the Brahamputra should be in higher flood than the Ganges, the river would probably take the course indicated at K. If, however, the Ganges should be in higher flood, the course would be at L, and the spur would return to the south bank of the Ganges.

In dealing with the training of such rivers, it is impossible to lay down any hard-and-fast rule. The conditions must be dissimilar in every individual case, and every river must be a study in itself. In some cases it is possible to put down permanent training works, whilst in others temporary training works must be undertaken, watching the results and guiding future operations by such results, for often unexpected results occur from the change in the course of a channel, far above the sphere of operation. Sometimes a mass of brushwood and trees brought down by floods may form the nucleus of a sandbank, which will completely alter the conditions previously existing. In some rivers where the cold weather channels meander about in a wide river bed, each channel requires careful study, especially in the earlier operations.

It often happens that a railway embankment traverses and blocks a very large area, over which the flood water has moved with more or less current, and the waterway to be given is, both for economical reasons and also for the better regulation of the flow, far less than even the defined bed of the river. It, therefore, becomes necessary to concentrate the channels, as far as practicable, into comparatively narrow compass. It is always advantageous to enlist the river itself into the work of training by checking the current at desired points so as to induce the deposit of silt. For this purpose various devices have been employed. In the earlier days of railways, brushwood groynes were almost exclusively used, but they are not durable, and they are costly in repairs; and though still extremely useful as preliminary and temporary training works to regulate the general course—to close dangerous channels, to prevent erosion, and to assist in the formation of more permanent training works—they have been, to a great extent, superseded by permanent embankments, protected from scour by loose stone or by concrete blocks. It is, however, seldom necessary to renew the temporary works when they have accomplished the results for which they were intended, for when a river has once been properly contracted into definite channels, the tendency to wander is much less than when the river bed is shallow and the channels numerous and straggling. It is dangerous, however, to push the policy of contraction too far, especially with those rivers which raise their beds, for it may give rise to a dangerous action at a considerable distance up-stream, which may induce the river to transgress its limits, breaking away altogether into new channels, devastating the country, and breaching the railway in the rear of the bridge. It very often happens that the worst floods are not at periods of greatest rainfall, but at those times early in the rainy season when a sudden flush comes down before the ordinary cold weather channels have had time to regulate themselves by clearing away the accumulation of silt deposited when the current has become sluggish in the dry season.

Plate XL. shows a continuous protection of loose stone on a permanent training work on the Kistna. Temporary training works may consist of piling, brushwood spurs, hurdles, fascines, sandbags, grass matting, earthen banks protected with grass bolsters or matting, and such other expedients as the locality may afford. A very useful temporary contrivance for closing troublesome channels is the "silt-weed" or "Brownlow" weed, as it is termed from its originator, General Brownlow, of the Royal Engineers. It is indicated in diagram at M, *Plate* XXXIX. The "silt-weed" consists of fascines or brushwood fastened together by grass ropes anchored at one end by rough anchors or stones enclosed in a coarse network of grass, and sustained by floats at the other end. The length of ropes to which the fascines or brushwood are attached should not be greater than twice the depth of the channel, otherwise it assumes a parabolic form and is not efficient. The flotation is generally effected by empty casks; the buoyancy of the silt-weed should be so regulated that the casks are nearly submerged. Ropes are generally made, about 8 inches in circumference, of coarse grass, anchored by grass-rope nets filled with stones weighing about 12 or 14cwt. The number of weeds and their distance apart must vary according to circumstances. Several rows of these weeds in succession have been found to be very effective in checking the current and causing a deposit of silt, and when a channel has been closed by their action, the casks and such portions of the weeds that can be removed are shifted for use in other places.

Where there is a well-defined bank to a river, the work of training is comparatively simple, and an embankment may be run out, as shown in the diagram at **N**, *Plate* XXXIX., and may be either continuous, with a coating of loose stone, as indicated at **O** and **P**, *Plate* XXXIX., but as this sometimes involves the wasteful expenditure of stone where the scour is concentrated, the protection is frequently intermittent, as indicated at **Q**, by throwing out spurs from the embankment and protecting their ends by loose stone, as shown at **R**, or preferably at **S**, which weakens the scour and forms a sloping foreshore between the two spurs, whilst an abrupt ending intensifies the scour.

The earthwork in such spurs is not infrequently affected by cross currents at the outset, but these may be counteracted by silt-weeds or temporary matting. When, as frequently happens, there is no defined bank, or when the distance to the bank is so great as to render this mode of protection impracticable, a different arrangement is necessary. Sometimes the railway embankment crosses a large flood area, in which the probable action of the water may be indicated by the arrows in Diagram **T**, *Plate* XXXIX., the current sweeping round, and tending to breach the embankment in the rear of the bridge. Such a tendency may be checked by running out an embankment, as indicated in Diagram **U**, *Plate* XXXIX., to induce dead water in the enclosure, tending to silt it up. In cases of greater magnitude, where the area to be reclaimed is very great, the space should be divided up by earthen embankments, as indicated at **V**, first taking care to silt up all back channels. The reclaimed space should be planted with trees or willows, or shrubs that produce undergrowth.

The River Chenab, where the railway crossed it, was $3\frac{1}{2}$ miles in breadth, its banks undefined, its bed of fine sand wandering through the plains, the banks falling wherever the current impinged on them, and villages constantly disappearing. The whole of its vast bed was intersected with numerous channels, and a large back channe crossed the railway 3 miles away from the main channel.

It was necessary to commence the training works $3\frac{1}{2}$ miles above the bridge, and about 4 square miles were reclaimed and planted. The bridge consisted of 64 spans of 129 feet each in the clear; this was far more than necessary to pass the water in flood times, but the training works were so gigantic that a greater contraction would have involved delay in commencing the bridge, and it was not deemed advisable to contract it further at that time. The effects of the training works subsequently enabled me to close a troublesome channel near the north bank, and to remove six spans for use in extensions urgently required during the Afghan War, but further training works did not admit of more contraction until several years afterwards.

In very large bridges it is desirable to keep the deep channels well away from the abutment, and with this view the first span has sometimes a continuous flooring of loose stone protection, about low-water level, as shown at **W**, *Plate* XXXIX., so that but little water will pass under the first span except when the river is in flood.

Sometimes comparatively shallow foundations may be adopted, and the protective flooring of loose stone may be carried completely across under the bridge, the flooring being lower at the centre than at the sides, as shown at **X**, *Plate* XXXIX., and a line of blocks or a drop wall may be run across the river to keep in the stone flooring. Some forms of brushwood groynes are shown at **Y** and **Z**, *Plate* XXXIX.

LECTURE VI.

BRIDGES.

Great care must be exercised in the selection of stone for bridge building. In one of my inspections I examined a specimen of stone from which a very large bridge with piers 40 feet in height was to be constructed; the stone was good-looking, reddish in appearance, and basaltic in formation. It was easily dressed, and to all appearance suitable to the work. A large quantity had been drawn from the bed of the river ready for the commencement of the bridge, but in the specimen I observed a very minute crack, scarcely perceptible, but it was sufficient to induce me to forbid the use of stone from that quarry until further experience had been gained respecting it. After a few weeks the crack became more apparent, and several months afterwards the whole of the stone that had been drawn for the site of the bridge developed similar cracks, and eventually broke up into small pieces. If the bridge had been built of such stone, it would have inevitably had to be re-built. When large masses of masonry are required, it is dangerous to use a lime that is not hydraulic. I have known instances of failure in masonry, the mortar of which when taken from the centre of the mass was almost as soft as when first laid, whilst mortar near the face of the work had set remarkably well. In India, the lime is frequently ground up with burnt brick, and the more intimate the grinding, the better the mortar.

In the hot weather, if a mortar be allowed to dry too rapidly, the set is lost, and it is generally the practice in the dry season to keep the top course flooded with water, leaving a little wall of mortar all round the edge of the masonry to keep the water in. With arches, it is necessary to keep the masonry well covered with wetted grass and matting, to prevent too rapid evaporation.

In piers and bridges where the height has been great, I have adopted diagonal joints, alternating with square joints, as indicated in Diagrams 1, 2, 3, and 4, *Plate* XLI., in order to make a complete bond; the courses, as shown in *Figs.* 1, 2, 3, and 4, being repeated alternately.

Masonry should be of the same character throughout. It is a great mistake to have a face-work of large stones filled in with smaller or inferior masonry, for the unequal settlement is apt to produce cracks. Large stone quoins in arches, or at the angles of piers or abutments, are objectionable for the same reason.

The native masons, if not sharply looked after, are very fond of what is termed "bread seal-masonry" (indicated in Diagram **A**, *Plate* XLI.). The face is formed of large wedge-shaped stones, the outer edges of which are easily dressed off to give the appearance of a good joint on the face, whilst the back is filled up anyhow. It is scarcely necessary to say that such a mode of construction must be at once condemned. Good *bedding* of the stone is of greater importance than good *vertical joints*.

It is important to secure a good outlet to culverts; the inlet, as a rule, gives but little trouble. If the outlet be on rock or hard ground, no special precautions are necessary. In moderately good ground on the level, it may be sufficient to lay in a drop wall, with perhaps a little loose stone as protection, as indicated at **B**, *Plate* XLI. In other cases, some sheet piling may be used with advantage, as shown at **C**, *Plate* XLI., supplemented by broken stone or brick rubbish, of which there is generally a residue from the construction of a culvert. But when the ground falls away rapidly, it may be necessary to have recourse to a water cushion, or a series of water cushions, to check the velocity of the outfall, as shown at **D**. In one case, in which the fall was considerable, and the volume not large, I have constructed a series of steps, each sloping back to carry a water cushion, as shown at **E**.

When rock is to be found for an outlet, it is always desirable to make the outlet on it; in some cases I have made the whole culvert in rock, merely blasting out a channel and arching it over, as roughly indicated at **F**, *Plate* XLI., or covering it with slabs, as shown at **G**, or else building a concrete arch over it, as at **H**.

In sidelong ground it is well to avoid, if possible, the placing of the culverts in the bottom of the ravine for two reasons—first, because the length of the culvert, if in the bottom of the ravine, must be made longer; and secondly, the rush of the water must be greater. Throughout the Ceylon incline I adopted the method of placing the inlet of the culvert as high as possible, and then running it on the contour of the ground at an inclination of 1 in 50 or 60. Out of 97 culverts, on an incline of 12 miles in length, I was able to treat all but three in this manner, and no difficulty has been experienced in any of them. Diagrams **J** and **K**, *Plate* XLI., indicate roughly the system adopted, the culvert being in the solid at one side of the ravine. A careful study of both sides of the ravine was necessary in the case of each culvert, to ensure the best ground, but more especially the best outlet, which was always, if practicable, brought to a spill over rock. Sometimes the culvert was curved to fit the contour of the ground; sometimes I have made the inlet some distance above the bottom of the ravine, in order to shorten the culvert or to obtain suitable ground, and have either filled in the space below the inlet or allowed it to fill itself in. In some cases in India, where water has been scarce, I have impounded the water, as shown in *Figs.* L and M, *Plate* XLI., leaving a by-wash or small culvert below formation level; but great caution is required in impounding water in this manner, for if the material of which the embankment is formed be not very impervious, the embankment may be carried away. In one instance I was rather anxious about an embankment behind which I had impounded water to a depth of nearly 40 feet. There was a considerable weep on the toe of the outer slope, but I had a quantity of clayey marl thrown into the water behind the embankment, and kept the water in a continual state of agitation, so as to stir up the clayey particles, which, being drawn by the water into the embankment, soon puddled it, and the weeping ceased. In some ravines, where the amount of water could not be great, and the embankment, being formed of rock, could not suffer, I simply put in a by-wash at a certain level as a precautionary measure; but, as I anticipated, the water was generally absorbed, and never rose to the by-wash. In fact, a ravine of this kind, when the embankment is formed from rock cuttings, has its bottom completely filled with huge pieces of rock, which, when tipped in the embankment, have rolled down to the very bottom of the ravine, making in themselves a perfect drain, which will pass a large quantity of water. *Plate* XLII., taken from a photograph of the Deckande culvert, on the Ceylon incline, is the largest specimen of the type of culvert on the contour. It is 20 feet in diameter. The embankment is about 80 feet high at the centre line, and 150 feet at the lower toe of the slope, which is about 100 feet below the apron of the culvert. In the execution of this culvert I decided to cut an outlet channel, so as to discharge the water into a small ravine adjoining the main ravine; the outlet is on solid rock. To have taken this culvert down the bed of the ravine would have involved a very heavy expense, and the rush of a large body of water through it would have been very destructive to masonry.

In some alluvial districts, where the foundation is light micaceous sand, liable to scour, but firm, and there is no necessity for spreading the weight of the bridge by an invert, as shown in diagrams N and P, *Plate* XLI., a protection of loose stone, as shown by diagrams Q and R, *Plate* XLI., is preferable; for if the water gets under the invert and allows scour, the invert falls in and is useless, whereas the loose stones accommodate themselves to the scour and prevent further erosion.

For moderate spans, arches are generally more satisfactory than girders, inasmuch as when once completed, they give no further trouble; whereas iron and steel girders require painting and general maintenance, and it is impossible to say how far the structure of the metal may alter with change of stresses and constant vibration, combined with corrosion.

Concrete in arches has been used more by Continental than by English engineers. Some very large arches, about 60-foot span, on the skew at angles varying from 18° to 30°, have been built in concrete, and one arch of 105 feet clear span, with a rise of 13 feet 6 inches, with a thickness of arch 20 inches at the crown and 2 feet 3 inches at the springing. The load on the haunches was lessened by spandrel arches, and the arch divided into two segments by flat asphalte joints at the centre and at the springing. The proportions of the concrete in the arch were one of cement, one of sand, and three of gravel.

It is necessary, in designing a bridge over a very large river, to determine the economic ratio of superstructure piers, so that the cost of the total number of spans erected complete should be about equal to that of the total number of piers complete with their protection. The cost of the pier does not vary appreciably with any increase or decrease of the span within moderate limits, and may, therefore, be considered a constant quantity. For rough approximations, I have found the following formula convenient:—
$C =$ the cost of one span of 100 feet erected complete (the 100 span being of a convenient type, its cost can generally be easily ascertained); $P =$ the cost of one pier, including its protection; $S =$ the approximate span in feet—

$$S = \frac{100}{\sqrt{\frac{C}{P}}}.$$

This will probably give a span slightly in excess of the economic ratio, but it is sufficiently near to assume a span for more detailed calculation, in order to determine the true economic ratio, and considering that there is more uncertainty respecting the cost of a pier than the cost of a girder, I have generally preferred to keep the cost of the superstructure rather in excess of the true economic ratio.

Plate girders are now seldom made of larger span than 50 or 60 feet. Beyond this span braced girders are generally more economical. When very small girders are used, the masonry of a bridge is apt to be shaken by the vibration of passing trains, owing to the small inertia of the girders. Plate girders, as a rule, are made of small depth, from $\frac{1}{12}$ to $\frac{1}{16}$ of the span. The quantity of metal in the top and bottom boom of any girder decreases nearly in proportion to the effective depth of the girder, whereas the bracing in a girder alters in quantity but very little with change of depth. This has led the engineers of the United States to extremes in the depth of their girders, some of which have a depth of $\frac{1}{4}$ of the span, but such girders, although economical in theory, are very shaky, and are liable to accident in the event of the derailment of the train; even a cow being thrown by a cow-catcher against the slender bracing of such a girder may wreck the bridge. There appears of late years to be a tendency in the practice of both countries to approach each other as regards the depth of girders. The Whipple-Murphy girder is perhaps the best kind of straight girder, admitting as it does of a good distribution of metal by minimizing the length of bracing in compression, but when the live load is great compared with the dead load, several of the bays must be counter-braced. Pin bridges are very much used in the United States, but the more modern practice tends rather to the English system of rivetted joints. In addition to the shearing area of the rivets, the compression of the rivets in cooling grips a joint, causing it to be much stronger than a pin joint that may have an equivalent shearing area of pin. Moreover, the parts in contact with each other suffer less from oxidation in rivetted than in pin joints. A pin structure is not so free from vibration as a rivetted structure, and even with the greatest exactitude of workmanship it is difficult to make all the pin joints take their fair share of the work. Pin joints in India have proved to be anything but a success. In many of such bridges I have examined, the links of the bottom boom have not taken their fair share of the strain, as is evident from the fact that some are not even strained to a straight line. The pin system is supposed to save weight and to facilitate erection, but these advantages are overrated.

Rivetting by hydraulic machinery, though doubtless a more perfect process than hand rivetting, and though valuable in the *construction* of girder work, can scarcely be used with economy in *erection*, where a few rivets have to be closed at one joint, and the machine then moved on to another. Machine rivetting is, however, valuable where steel rivets are used, for some steel, if subjected to concussion at a blue heat, is apt to deteriorate. Some years ago I had some experiments made on steel which bent double when cold, or at red or white heat, but when worked at blue heat under a hammer it went to pieces. As a rule, I have preferred to specify, for girder work, iron rivets of good quality rather than steel.

Whatever may be the design of a girder bridge, it may sometimes happen that its erection is almost as costly as its first manufacture, and requires, perhaps, as much technical knowledge and experience. There are many modes of erection, such as—

Erecting in position on staging.
Hoisting, or raising whole.
Rolling out.
Floating out.
Erecting by building out.

The design of a staging varies according to the materials available for its construction, and the character and depth of the space to be bridged. Sleeper stacks, earth banks, timber staging, or piling, timber trestles, screw piles, and specially designed iron staging have all been used for the erection of girders. Sleeper stacks are nearly always available, and save expense; they can be easily taken up and put down, and are useful where the height is not great. Earthen banks are of limited application, and can be only employed when the height is small. The timber used in staging is sometimes subsequently cut up for the flooring of bridges. Trestles may be either vertical or sloped, as those which I have already indicated in *Figs.* 1, 2, and 3, *Plate* XXXII., used for the sinking of hydraulic piles. Light screw piles may be often usefully employed, and afterwards unscrewed to be used elsewhere.

Plate XLIII. shows two different kinds of iron staging, which I designed for rapidly pushing on the railway communications between Pindi and Jhelum for war purposes. They were of two kinds, one being composed of light wrought-iron columns in 9 feet lengths, easily handled, all bolt holes being drilled to template, so as to be interchangeable. The other kind, formed of light braced angle-iron pillars, also interchangeable, and capable of being made up into bays of four, six, or more, according to circumstances. These bays supported light girders on which the platform rested. Sometimes the connecting girders were spans of 20 or 30 feet, eventually to be used permanently for small bridges on the same railway. These bays are easily put together and taken down, but they are stronger and heavier than are actually necessary in the majority of cases, being designed by me so as to be able, in case of emergency, to support the girders for traffic in case the progress of the masonry should have been insufficient to complete the piers in time; but they have been extremely useful, having been employed subsequently in different parts of India. Iron staging of a lighter character is shown in *Plate* XLIV., taken from a photograph of the bridge over the Narbudda river, the bays being made up of small iron piping, bolted together and properly braced. The plan of erection on staging is, as a rule, the most simple and safe; and where the bridge is not high and the water shallow it gives rise to very little complication. When there is a difficulty in the erection of staging in the middle of a river, or danger of the staging being washed away, a fan-shaped erection may be adopted with advantage.

The Sohan bridge, shown in *Plate* XLV., is a case in point. This bridge was urgently required to complete communications during the Afghan War, being the key to opening the line, and it had to be erected during the rains, when sudden and violent floods might at any time be expected to wash away the staging. So great, however, was the necessity for completing communication that it was determined to risk the girder. My son, who was in charge of the work, designed and constructed the staging, and then erected the girder with such despatch that it was perfectly safe from danger in 28 working hours after the first portion of the girder had been risked on the staging. The iron staging I have already described may be seen on the left-hand side, combined with a sleeper stack. The Attok bridge, supported on steel piers, shown in *Plate* XLVI., was subsequently erected over the Indus on a similar principle, and is probably one of the finest examples of this method of erection. An elaborate system of trestle work sprung from the feet of the piers, and was braced to them in fan shape, enabling the spans of 300 feet, weighing each about 600 tons, to be erected in position. *Plate* XLVII. shows the central portion of the staging being hoisted, *Plate* XLVIII. shows the span completed, and *Plate* XLIX. the whole bridge completed.

Plate L. shows the erection of bow-string girders of the bridge over the Bukkar Channel of the Indus, the vertical members being placed in position. *Plate* LI. shows the girder completed; the staging is composite, consisting partly of both kinds of my iron staging and partly of timber fan staging. *Plate* LII. shows the adjoining span completed; the water being shallow, the girders were erected entirely on my cylindrical iron staging. *Plate* LIII. gives a view of the bridge over the Chuppar Rift on the Kandahar Railway, the main span being 150 feet and the smaller spans each 40 feet. The erection was effected by fastening together some spare girders which were to be used further along the line, and these, inverted and rolled across the gap, supported the staging on which the girders were erected. *Plate* LIV. shows the bridge completed.

In the majority of cases it is not desirable to hoist the bridge materials from below, but more economical to run them on from one end, the exception being when the material is delivered by water.

The method of hoisting or raising the whole span complete has been carried out successfully in many places. The first instance of any magnitude was that of the Britannia Bridge over the Menai Straits, which was floated into position and raised by hydraulic presses, grooves being left in the masonry to allow it to be hoisted. In lifting, it is always necessary to follow up with packing, so that in the event of any failure in lifting gear the girders may be safe. In some cases the girders have been erected complete, and raised by hydraulic ship-jacks as the masonry progressed, but this is apt to interfere with the progress of the masonry. In tidal rivers, where the rise is great, the tide may form a simple and manageable mode of lifting girders.

Adjusting screws, shown in *Fig.* 1, *Plate* LV., will be found convenient for adjusting the camber of girders when laying the lower boom. *Figs.* 2 and 3, *Plate* LV., show a very simple form of crane for erection when the weights of the pieces to be lifted do not exceed a ton or a ton and a-half; it is formed out of old rails. For rivers in which the bed is nearly dry in the hot season, as was the case in the Chenab River, the girders may be erected in the bed of the river and hoisted bodily by two Wellington cranes into position, as indicated at *Fig.* 4, *Plate* LV. Sometimes a wire rope has been used to support a 60-foot span girder over a deep ravine, the girder being slung to a block running over the rope, as indicated in *Fig.* 5, *Plate* LV. Small spans, up to about 20 feet, may be slid or rolled across on rails laid across the span. In larger girders, where the river bed is dry, the bridge may be rolled out on staging by means of a Wellington crane, as shown in *Fig.* 7, *Plate* LV.; where the water is deep they may be floated out, as indicated in *Fig.* 6, *Plate* LV. In such cases the boat must be secured from lateral rolling movement under the girder, otherwise it may capsize. If the staging be very high, it is better to employ a pair of boats. In the case of the Ravi bridge, on the Punjab Northern State Railway, two pairs of native barges were arranged with staging 16 feet high, the remaining height being made up of sleeper stacks, so as to allow for changes in the level of the river. The girders were erected on the shore, and traversed about 400 feet on to a staging of timber piles carried out to a sufficient distance to obtain depth to float the barges. The girders were first traversed by a Wellington crane until one end rested on the staging of one pair of barges, the crane was then run back to lift the other end of the span and carry it slowly forward so as to rest on the staging of the second pair of barges, which were floated underneath the girder as the first pair of barges moved off, carrying the end of the girders. The two pair of barges, with the span resting on them, were then floated into position, and the girders lowered on to the piers by means of screw-jacks and wedges. The girders were traversed about 400 feet, then transferred to the barges, floated out, and lowered on to the piers, as described above, at the rate of three or four spans per day.

On the Madras Railway plate girders of 70 feet span were constructed in continuous lengths of two spans each, so that each girder has three bearings, one at the centre and one at each end. These double girders were put together at one end of the bridge and hauled over on to the span. In some cases of erection the staging is carried out only for a short distance from each abutment, where the water is shallow, and the girders rolled out overhanging until they reach the staging built out from the opposite abutment, one end being weighted to balance the overhanging portion. In other cases staging has been altogether dispensed with, the girders being balanced by a spare girder attached to them temporarily for the purpose of erection. Caution, however, is necessary in erection of this character, from the fact that those portions of the girder which are intended only to bear stress in *tension* may be brought into *compression* when the girders overhang. It may be necessary, therefore, to strengthen such portions by temporary supports of timber, or otherwise, to enable them to resist such abnormal strains.

When girders are built out, they should be specially constructed for that purpose. The Forth Bridge, of the "cantilever" type, is the finest example of erection by building out; it has been so frequently described in the public journals that it is unnecessary for me to do more than allude to it. *Plate* LVI. shows the completed bridge. *Plate* LVII. shows the commencement of the work of building out, and the cages and appliances made to enable the workmen to work on the overhanging portions. The Bläau Kranz Viaduct, in

South Africa, is an instance of bold erection by building out. *Plate* LVIII. shows the first stage of building out, *Plate* LIX. the next stage, and *Plate* LX. the viaduct completed. The most notable case of building out arches is that of the steel arch over the Mississippi, in which great difficulty was experienced in the meeting at the crown of the arch from the expansion and contraction with the varying temperature, and it was necessary to have recourse to the use of ice to cause the arch ribs to contract sufficiently. *Plate* LXI. is a sketch design I made for an arch of 830 feet span, with a rise of 150 feet, to be built out over the river Indus at Sukkar; the difficulty of meeting at the crown in this design was met by hinging the arch at the springing as well as the crown. It would have been the most economical form of bridge for that particular position had a double line of railway been necessary. It was not, however, executed, as it was decided that a single line only was necessary for crossing the Indus, and the arch, as designed by me, needed two lines of railway in order to afford it sufficient lateral stiffness, whereas a bridge on the cantilever principle could give sufficient lateral strength with a single line. *Plate* LXII. shows the bridge that was finally adopted from the designs of Sir Alexander Rendel. *Plates* LXIII., LXIV., LXV., and LXVI. show the mode of erection. *Plate* LXVII. shows the span completed but the central support between the cantilevers not removed. *Plate* LXVIII. exhibits a very curious bridge I saw in the Rocky Mountains of Colorado. The whole of the bottom of the ravine was occupied by the river, rendering it impossible to put in a pier. The girders on one side were supported by the solid rock, whereas those on the other side overhanging the river were suspended, as shown, from iron supports abutting against the sides of the ravine.

In the design and erection of bridges, the probable effects of the wind must not be neglected. *Plate* LXIX. shows the results of a cyclone on a bridge in Mauritius. In one case some girders of 150 feet span on the South Mahratta Railway were blown off their expansion rollers, which in this case were cylindrical, showing the necessity either for flanges or for support of some kind to prevent lateral movement.

Plates LXX. and LXXI. show the effect of wind on the rolling stock of the Mauritius Railway. *Plate* LXXII. shows the effect of the wind on the carriages of an Indian railway of the mètre gauge.

LECTURE VII.

PERMANENT WAY.

In the selection of ballast there is a variety of choice, the principal consideration being first cost and facility of supply. Wooden sleepers require more careful selection of ballast and more perfect drainage than metal sleepers. Care should be taken to adopt a ballast capable of easy drainage and not readily crushed.

Gravel makes a very good ballast, but it should be tolerably clean, and of a character that will not bind. River shingle mixed with coarse sand is also very good; but rounded shingle, if too clean, is apt to shift under the sleepers, and requires constant attention. I have found it, in this respect, easily remedied by the addition of ballast which in itself would be of an inferior character. Coarse sand makes an excellent ballast, especially for metal sleepers; but in dry climates fine sand is apt to be blown by the wind of the passing train into the axle-boxes and machinery, producing serious wear. This may to some extent be remedied by covering the surface of the ballast with a layer of gravel or other heavier ballast, but in course of time the two get gradually mixed in maintenance.

In some districts, where the soil is an alluvial sand slightly mixed with clay particles or loam, I have known iron sleepers to be laid without any ballast, and the grass allowed to grow over the surface keeping it from blowing about; but if there is much clay mixed with the sand, the plan does not answer. In any case, it is unsuited for timber sleepers, which should be kept as dry as possible, to prevent decay.

In India there is a material termed "Moorum," which is frequently obtained from cuttings, and is of a character apparently like a soft sandstone, but which, after a few months' exposure, disintegrates into mud, and is a most unsatisfactory material for ballast.

Broken stone makes an excellent ballast, but when used for metal sleepers it should be broken somewhat small.

Machinery for breaking up stone is not, as a rule, satisfactory. It breaks a stone into inconvenient forms for ballast, and grinds too much to powder. Where labour is cheap, as in India, stone-breaking by machinery is more expensive than by hand. In alluvial districts, such as the Delta of the Ganges, where stone is not to be obtained, it is necessary to have recourse to burnt clay or brick ballast, but such ballast is, as a rule, unsatisfactory and expensive in maintenance, breaking up from the effects of packing, and from the weight of trains, and forming a fine powder, which blows into the machinery. If broken stone or gravel can be obtained, even at considerably increased cost, it may be advisable only to put in bottom ballast of brick, and as soon as trains can be run through to a district in which better ballast can be brought, to top up with the more suitable material. Where brick earth is used for ballast, it should be burnt nearly to vitrification; kiln clinkers and the refuse of brick-making are often of this character. Some kinds of ballast contain salts, which cause rapid corrosion in iron sleepers. I have sometimes found pieces of cast-iron pot sleepers ⅜ inch in thickness so corroded that I could break it like a biscuit. Ballast containing such salts should not be used for metal sleepers.

Care must be taken in forming the embankment to receive the ballast to slope it properly, so as to throw the water from the centre; the slope from the centre to the sides is generally about 1 in 30. The consumption of ballast in high embankments is in some cases enormous, owing to the insufficient drainage of the roadway. I recollect one case in which a new line on a clay embankment became quite impassable during the rains; the ballast, added from time to time, had sunk into the clay, forming, as indicated in Diagram 1, *Plate* LXXIII., a cavity, which was filled with water, the weight of the passing train forcing up the liquid clay through the ballast. This process was repeated to such an extent, that the ordinary traffic had to be stopped, a few trains of sand, worked out carefully, the line lifted on to sand, and the bank cut through every 30 feet to let out the accumulated water; until the water was drained, it was useless to attempt any remedy.

In clay cuttings, also, the liquid mud is sometimes churned up between the sleepers, and the ballast sinks down as it is packed under the sleepers until troughs, filled with ballast and water, as shown in Diagrams 2 and 3, *Plate* LXXIII., render it impossible to keep the road in good order. When this happens, the only remedy is to remove the whole of the clay and ballast in sections, to be replaced with sand and new ballast, first filling in a layer of large stones to form a base, and the whole cutting should be drained completely.

Time and labour can be economized in handling rails by use of rail forks to take the web of the rail, combined with the use of swivelling rollers mounted on light tripod stands about 2 feet 6 inches from the ground. The rollers may be moved about to any position required. They should be distant apart from each other about half the length of rail, and when drilled in the use of them, a single man is able to move a rail rapidly about, passing it from roller to roller, and, balancing it by its middle on one roller, he can swivel it round to the next roller in whatever direction it may be, so that if rollers be laid down he can suddenly change the direction of the rail, if desired, at right angles to its previous position. The Diagrams 4 and 5, *Plate* LXXIII., show the general character of the fork, the rollers are shown at 6 and 7, and the manner of using them in Diagram 8, *Plate* LXXIII.

It generally happens that the rails and sleepers arrive before the line is ready for them, and have to be stacked in the store yard, and when rails have to be laid telescopically, great confusion and delay will arise if proper systematic arrangements be not made for their loading up. If it can be so arranged, the siding for loading should be in cutting below the general level of the store yard, somewhat as indicated in the diagram 9, *Plate* LXXIII.

The loading of the trucks may be rapidly effected by means of a sloping platform of rails kept well greased, on which the rails are slid down one after another by a couple of men with hook ropes, which they attach to the fish-bolt holes. For laying telescopically, the rails are loaded in the train in waggons in front of the sleepers. The most convenient waggons for this purpose are low-sided or platform waggons; bogie waggons which take the full length of the rails will be the most convenient, but if these are not available, rails on one waggon should be packed up on bolsters or sleeper stacks so as to overlap those in the next. Timber trucks with swivelling bolsters may also be used with advantage. About half a mile of permanent-way is carried in each train. For the 5-foot 6-inch gauge, a train of about 15 waggons of 10 tons carrying capacity each, with one brake van, are required, or smaller number of 20-ton bogie waggons.

When the train reaches the station or crossing place nearest to the rail head, or the part where the operations are being carried on, the engine is placed at the rear of the train, which is cautiously pushed up as close as practicable to the rail head, and unloaded with despatch. Two light trollies, loaded over-night with fish-plates and fastenings for the next day's work, are kept close up to the linkers as they advance. Trollies for rails and sleepers are divided into two sets, one set being loaded whilst the other is following up the linkers closely. The return trollies are lifted off the line to allow the loaded trollies to pass when they meet them. Where wooden sleepers are employed, each rail as it is laid is roughly laid and secured by three spikes half-driven to allow the trollies to follow closely. A few swivel rollers at the rail head, moved forward from time to time as the work progresses, may be usefully employed for handling the rails. It is always necessary in telescopic laying to leave behind sufficient and constantly increasing gangs of platelayers to maintain the road in good order. In some cases, where ballast cannot be readily obtained, it may be necessary at the outset to lay the permanent-way directly on the formation without ballast. If proper care be not taken this will result in bent and hogged rails, which entail much cost and trouble in straightening and permanent injury to the road, which can seldom be made to run well or smoothly afterwards; but this is due, as a rule, to want of proper and ordinary precaution, and neglect to the maintenance of the way. The formation in such case ought to be properly and carefully prepared, so that the sleepers bear fairly upon it, and when ballast is on the embankment in some places and not in others, the change should be sloped off gradually at the ends; but, above all, it is essential that sufficient gangs of platelayers should be kept constantly at work maintaining the road in proper order. If this be done, the bending of the rails may be avoided. I have seen permanent way with transverse steel sleepers laid on the formation absolutely without ballast, and construction trains run over the rails without the slightest injury, where the embankment was formed of earth. If rocks or boulders are present in the bank, it will be necessary to pack the sleepers very carefully to avoid injury. In laying a road with wood sleepers, the spikes may easily be driven without boring holes for them, but this should never be done. Holes for the spikes should be bored quite *through* the sleepers with an augur of about half the diameter of the dog spike. Few people have any idea of the mischief that is done when a spike is driven into a sleeper without boring a hole for its reception. The fibres of the wood are crushed, and frequently large splinters of wood are forced out from the bottom of the sleeper.

In one of my inspections, the foreman of platelayers complained to me that the spikes were bad and would not hold, but that they came out when the train passed over them. Guessing what was the matter, I had one of the sleepers taken out, and found, as I had expected, that a large splinter had been driven out, as indicated in Diagram No. 10, *Plate* LXXIII., and the point of the spike rested upon it, so that it was forced up as soon as the pressure of the engine came upon the sleeper.

In laying rails, especially in tropical climates, it is most important to make proper allowance for expansion. Without this it would be impossible to keep the rails straight in hot weather, and in cold weather the fish-bolts will shear and sometimes rail ends split. I have seen joints, as shown in the Diagram No. 11, *Plate* LXXIII., in which the top table has been forced up in consequence of the contraction due to excessive cold. In this case special allowance had not been made in the bolt-hole. A handy form of expansion block is shown in the Diagram 12, *Plate* LXXIII., one side being thick and the other thin, either to be used as required by the variation of the temperature.

In laying a line care must be taken to place the rails as nearly as possible in the permanent position, otherwise the allowance for expansion may be lost in slewing the line when straightening it up. Rails are generally made in even lengths of 7, 8, 9, or 10 yards. There is usually a certain percentage of rails of shorter lengths as well as a percentage of rails 3 inches shorter than the standard, the latter being useful in saving cutting when the inner rail gains on the outside rail on curves. To distinguish such rails from those of standard lengths, their ends are sometimes painted, but the paint is apt to be lost in transport or from the effects of rust, and the more durable plan for distinguishing them is to have a third bolt-hole to such rails. If necessary, these rails, when not required to bring the joints even or opposite one another, may be used in pairs.

Rails are sometimes laid with "breaking joint," *i.e.*, the joint of one rail opposite the middle of the other. In a line which abounds with curves, the breaking-joint will save the trouble of cutting rails or adjusting the joints by short rails to bring them opposite to each other.

Commencing with the joint of one side of the track opposite the mid rail at the other side, the sleepers are so arranged as to be at nearly equal distances apart but drawn slightly nearer together where the joint happens to come. If one joint is found to be gain-ing too much on the other, a rail one or two yards shorter may be inserted so as to bring it back again near to the mid rail. A track laid with breaking-joint is laterally stronger, in the proportion of 10 to 7, than when the joints are opposite each other. I had a length of 10 miles of permanent way laid down experimentally on two different railways, and on asking the opinion of the permanent-way inspectors as to the relative merits of break-joint and opposite-joint, the first told me that the break-joint gave more trouble in first laying, but was more easily maintained; but on the other railway I was told that the first laying was less troublesome, but was more difficult in maintenance. It is doubtful whether there is any marked advantage, in these respects, in either system. Passing from one system to another on an engine, it seemed to me that the break-joint produced rather the smoother running.

In laying permanent way telescopically it is frequently necessary to make temporary diversions to pass an unfinished bridge or culvert, and in many cases I have found such diversions improperly constructed, as indicated in Diagram 13, *Plate* LXXIII., instead of being made as indicated in Diagram 14. Such diversions must necessarily be on steep inclines, and if the curve be on the incline the power of the engine for haulage is greatly diminished; therefore, instead of putting the curve on the incline, it should be confined to the level portions, and this is generally practicable.

Transverse wooden sleepers have many advantages; they can be procured in many countries locally, but in the tropics many of the woods decay very rapidly, though some of the harder timber, such as oak, saul or ironwood, are very suitable for sleepers and very durable. The time of year at which timber is felled has a great influence on its durability. Sleepers should be cut as long a time as possible before they are used, and stacked with spaces between them for ventilation. The stacks should be at least 5 feet distance from each other, and a space equal to a sleeper's width between each sleeper. Not more than about 50 sleepers should be on one stack, and the stacks should be protected from sun and rain by matting or otherwise.

Although broken rock ballast affords better drainage than sand or gravel, yet timber sleepers, especially those of soft wood, are sometimes destroyed more rapidly by pounding upon it than by decay in gravel or sand. The best length for a transverse wood sleeper is about 1¾ of the gauge. Creosoted Baltic sleepers have not, as a rule, proved to be satisfactory in India.

Bed-plates, or chairs, should be used with soft wood sleepers; they distribute the pressure of the rail on the sleepers; they avoid the necessity of adzing the sleepers, which tends to set up decay; they stop any tendency of the rails to tilt, and increase the lateral resistance of the spikes, which help each other when connected by a bed-plate, whereas without a bed-plate the spikes on one side of the rail alone resist lateral movement. It is necessary, however, that the bearing-plates should be of sufficient strength and thickness to prevent their bending. The bed-plates, indicated in Diagrams 15 and 16, *Plate* LXXIII., are rolled to the section shown at 16, and cut into short lengths; in some cases projecting ribs, as shown, or a net-work of small diagonal ribs, are rolled on the bottom of the bed-plate to give it a good hold on the sleeper. Too long a bearing of the rail on the sleepers causes the sleepers to rock, and to increase the cost of maintenance.

For wooden sleepers, fang-bolts, shown at 17, *Plate* LXXIII., are not at all satisfactory; they form a strong fastening at first, but in a short time they rust, and when they work loose they cannot be taken out. Coach screws, shown at 18, *Plate* LXXIII., have been used in India for the same purpose, but they become useless after a short time. Oak trenails are sometimes used with chairs for double-headed rails; they hold well, but they are apt to be sheared off unless assisted by iron spikes. Spikes for this purpose are shown at 19, *Plate* LXXIII.; they are generally round, with "pan head." Those used for flange rails are generally rectangular in section, with parallel sides, as shown at 20 and 21, *Plate* LXXIII. The best form is chisel-pointed, so as to displace the grain of the wood endways, the length of tapering point being about twice the diameter of the spike. They have generally a small lug on each side of the head for facilities of drawing them. The highest portion of the spike should be over its centre to enable it to be driven straight. A spike should not be driven after it is brought in contact with the rail; it frequently happens that injudicious driving will snap off the head, as shown in Diagram 22, *Plate* LXXIII. Taper spikes have less adhesion than parallel-sided spikes. No advantage is gained by jagging the spikes; it lacerates the fibre of the wood and, if anything, lessens the adhesion. Twisted spikes have been tried but found useless. Compressed oak keys are very generally used for securing double-headed rails and chairs, but in a sea voyage they sometimes absorb moisture and expand so that they cannot be driven without adzing them down. In the tropics the great hydrometric changes render the use of wooden keys very undesirable; in the hot weather they shrink, and if they do not fall out under the vibration of the train, they allow the rail to hammer in the chair. Keys of coiled iron, and steel keys bent round so as to form a spring, have been employed to remedy this defect, but their use has not been attended with success.

The earliest form of metal sleeper that has been largely used is the cast-iron "pot" or "bowl sleeper," shown in *Figs.* 23, 24, and 25, *Plate* LXXIII. It has under the rail two small pads of wood, and the pair of bowls connected together by a transverse bar of wrought iron form one sleeper.

These sleepers have been found in India, on the whole, to be very economical in maintenance compared with wooden sleepers, when the ballast is suitable. On one railway I found the annual percentage of renewals in sand ballast to be less than 3 per cent., whilst on another railway with rock ballast, broken too large, it was nearly 30 per cent. Packing under the concave surfaces is somewhat difficult with these sleepers, and the wooden pads are not satisfactory; after a time they get as hard as iron, and it is necessary to cut them out with a chisel when they require removal. Felt and soft material interposed between the rail and the sleeper is worse than useless. De Bergue's sleeper (*Figs.* 26, 27, and 28, *Plate* LXXIII.) is an improvement on the pot sleeper. The fastening is more satisfactory, the sleeper settles itself in the ballast, and is more easily packed than the concave surface of the pot sleeper. The Denham Olphert sleeper (*Figs.* 29 and 30, *Plate* LXXIII.) has been largely used on the East Indian Railway, and appears to have given great satisfaction. It is easily packed, and the rails being supported under the top tables, the lower tables are not indented by concussion (*Figs.* 31 and 32, *Plate* LXXIII., show the adaptation of the Denham Olphert sleeper to the flange rail). One great advantage of cast-iron sleepers is that the corrosion is small, and the metal is always capable of being re-cast in the event of breakage or wear.

Vautherin's wrought-iron sleeper (*Fig.* 33, *Plate* LXXIII., and *Figs.* 1, 2, and 3, *Plate* LXXIV.) has been much used on the Continent. I have tried it in India and found it very satisfactory. *Fig.* 1, *Plate* LXXIV., shows the section of the sleeper, and *Figs.* 2 and 3, *Plate* LXXIV., the details of the fastening. The objection to this sleeper is the multiplicity of fastenings and their tendency to rust together. The ordinary transverse "pea-pod" steel sleepers (*Fig.* 4, *Plate* LXXIV., and shown in section at **A**, **B**, and **C**) have been very largely used in India, and have been found to be most satisfactory, except where the ballast contains corrosive salts. It is extremely simple, the rail being fastened to it by a taper steel key, shown in *Figs*. 5 and 6, *Plate* LXXIV.; and allowance in gauge for curves is given by driving one or both keys on the *inside* of the rails. When both keys are *outside* the rails, the line is to standard width of gauge. There seems to be no tendency in these keys to shake loose. The thickness of the metal should not be less than half an inch at the fastening or a quarter of an inch in the body of the sleepers. It is a mistake to attempt to economize too much in the weight of a sleeper; a certain amount of weight is necessary, and a transverse metal sleeper of the ordinary gauge should not weigh less than 150lbs. I am inclined to prefer a simple rolled sleeper of the uniform section, shown in Diagram D, *Plate* LXXIV., and with fastenings similar to those of the "pea-pod" sleeper, as more simple in manufacture and more easy to pack than the "pea-pod" sleeper. The ends of the sleeper should be left open. Nothing is gained in lateral stability by closed ends; for filling in ballast at the end of the sleepers does not practically increase the lateral resistance, which is directly proportioned to the weight with which the sleepers are pressed on the ballast. Too long a bearing of the rail causes the sleepers to rock. Transverse sleepers should not be allowed to bear on their centres, and the ballast should be arranged as shown by dotted lines in *Fig.* 4, *Plate* LXXIV., and drained between the sleepers.

Failure is more instructive than success, and *Figs.* 7 to 14 inclusive, *Plate* LXXIV., show the principal, though by no means all the types of longitudinal rails that have been adopted and have been more or less failures. *Fig.* 7 is the Adams' girder rail; 8 the bridge rail used on the 7-foot gauge of the Great Western Railway; 9 is a double-headed rail on cast-iron supports; 10 a flange rail on a longitudinal saddle; 11 is Macdonnell's sleeper on cast longitudinals; 12 is a double-headed rail between two baulks; 13 is Seaton's rail on timber longitudinals, triangular in section; 14 is Barlow's saddle rail; 15 is Adams' suspended rail used on the Bombay and Baroda Railway; 16 is a double rail used on the Continent, also a failure; 17 and 18 are rails for street railways, and, except for such purposes, longitudinal sleepers may be said to have been abandoned. Practically the only types of rail that are in general use on ordinary railways are the flange or "Vignoles" indicated in Diagram 19, *Plate* LXXIV., the bull-headed at 20, and the double-headed at 21. The flange rail is almost universally used, except in England and some of its dependencies. The original idea of the double-headed rail was that the rails could be turned, and would then last as long as a new rail. Practice, however, has not altogether confirmed this view; the rail becomes indented by hammering on the chair, and when turned it makes a very rough road, injurious to rolling stock. Moreover, when a rail has been much run over, the metal appears to accustom itself in time, as it were, in certain stresses in tension and other stresses in compression, and when these stresses are reversed by turning the rail, the metal appears to fail rapidly. The double-headed rail is not so strong laterally as a flange rail; it is more difficult to secure, and the constant changes from moist to dry cause the wooden keys which secure it to expand and contract alternately, rendering it very difficult to keep the road in order. In the tropics these changes are much greater than in England. The bull-headed rail is a compromise with the double-headed rail; it is a tacit admission of the practical difficulty of turning the rail and endeavour to construct a rail with many of the disadvantages of a double-headed rail, whilst its only advantage is that, with a given weight, it admits more metal in the top or wearing table of the rails. The flange rail is by far the most simple; it is easily secured and maintained, and for all practical purposes it is far the best for adoption in a new country.

Iron rails are almost extinct, having been superseded by steel rails. It used to be the practice to notch the flange of rails to check their tendency for travelling, but this has been found to injure the strength of the rail, setting up a crack and causing the rail to break through the notch with rough handling. Angled fish-plates, or check-plates, are more suitable to check this tendency. When rails are used on very sharp curves, or turn-outs, they have to be bent, but care should be taken not to bend them in what may be termed a "dog-legged" manner. A very efficient form of rail press is formed by three rollers, the central roller of which is screwed down to give the required curve, and the rail drawn through and bent throughout its length, the rollers being grooved, so as to loosely fit the shape of the rail. If a screw press be used, it should be furnished with a stop to prevent the bending of the rail too much at one point. Excepting on curves of very sharp radius, rails may be sufficiently bent with a bar, and no special bending is required before the rail is put into the road.

Care should be taken to give a proper cant to the rail, generally 1 in 20. Wooden sleepers should be very carefully adzed to the proper cant, unless a canted bed-plate is used. Improper canting injures the tyre, which, in its turn, reacts upon the rail. The Oudh and Rohilkund Railway, as originally constructed, had no cant to its rails, and the tyres of the rolling stock were cylindrical instead of coned, so that when the waggons and carriages of other railways passed over the line their tyres suffered and they injured the rails; in like manner the rolling stock of the Oudh and Rohilkund Railway suffered when it passed on to other railways.

On very sharp curves, or in dangerous places, such as curved approaches to a bridge, it is usual to put a guard rail inside the inner rail, and where the gauge has been increased to allow for the curve, the guard rail must be laid with reference to the position of outer rail; in fact, the clearance must be increased directly as the increase in gauge, for the flange of the wheel will bear against the outer rail, and if the guard rail should prevent this, the inner wheel will grate unpleasantly against the guard rail, and will probably break the fastenings.

Rails are often made with too small a radius for the top table, causing undue wear both of rolling stock and rails, until the rail itself is worn down. The radius of the top table should not be less than 15 inches, and some engineers recommend a radius of 2 or 3 feet. The radius of the shoulder should be about $\frac{5}{8}$ inch; the thickness of the web may be from $\frac{3}{8}$ inch to $\frac{1}{2}$ inch for rails up to 75lbs. weight. The length of rails generally in use now is about 30 feet. They can be rolled in longer lengths to save joints, but in such lengths they are difficult to handle; in fact, where there is much land carriage of an expensive character, it may be desirable to adopt even shorter lengths. Heavy rails weighing as much as 100lbs. per yard are sometimes adopted, but they are difficult to handle and less elastic than the lighter rails, and it is questionable whether better results cannot be obtained with lighter rails, say about 75lbs. to the yard, and a slight increase in the number of sleepers.

When commencing a line in a new country, the class of permanent way to be laid down, and the weight of rails to be adopted, must depend upon the traffic that may be expected. When the traffic is likely to be small, it may be well to lay down a light rail in the first instance, and renew with heavier rails as the traffic increases; but, at the same time, it must be remembered that a light rail limits the wheel load, and consequently the efficiency of the engines, and the traffic is, as a rule, far greater than statistics of existing traffic would indicate.

In steel rails, the best angle for fishing is about 15° from the horizontal line when the rail is upright, as indicated in *Fig.* 19, *Plate* LXXIV. In modern practice the tendency is to increase the strength of fish-plates by producing them below the level of the bottom of the rail, as shown in *Fig.* 22, *Plate* LXXIV., to give additional depth. The suspended joint is generally preferred to the insistent joint. Adams' insistent fish-joint, shown at *Fig.* 25, has been tried, but was not satisfactory. Ibbottson's fish-clip, shown at *Fig.* 26, has also been tried, but was very unsatisfactory, chiefly owing to the difficulty of making a proper fit to the rail. In one case I found the sand had collected in the clip and prevented the expansion of the rail; this was remedied by boring a small hole in the bottom of the clip under the joint. Holes in the rails for fish-plates should be oval, to allow for expansion.

Fish-plates have generally four bolts to a pair; in some cases five bolts have been used, one bolt being in the centre, and the ends of the rails being notched to admit the central bolt. This prevents any spring of the fish at the centre. In some cases, six bolts have been used, but it has been found that, when injudiciously screwed up, the grip of the fish-plates was so great as to prevent a proper expansion of rails. Fish-plates have been used thicker at the middle than at the ends, as shown at *Fig.* 28, *Plate* LXXIV., but this renders their manufacture difficult, and it is doubtful whether any advantage is gained by this form. Bolts and cotters have been used as shown in *Fig.* 24, *Plate* LXXIV., the tendency of the fastening being to shake tight with the vibration of the train; the objection to them is that they afford so little surface to bear the stress.

It is very important to have an efficient fish-bolt, and many expedients have been proposed in the shape of lock-nuts, spring washers, etc., but it is doubtful whether they will be permanently efficacious. Some lock-nuts have been used with more or less success in preventing the nuts from slackening, but there is a danger of the threads rusting in the nuts, so that they cannot be removed without breakage; this is not the case where nuts are being constantly tightened up by the plate-laying gang. In maintenance, great care should be exercised in always keeping up the road in first-class condition; if once the joints get down, and the ends of the rails are worn to any extent, it is almost hopeless to maintain a good joint, and the road will always run roughly.

Cast-steel reversible crossings are much used, and they have many advantages, but they are somewhat rigid, and cannot be eased off to suit different conditions so easily as built crossings, though they are more durable. One disadvantage is that sharp angles necessary sometimes cause the lug which takes the rails to snap off, as indicated by the dotted line in *Fig.* 26, *Plate* LXXIV., making the crossing useless. This is generally due to carelessness on the part of the plate-layer. There is more jar in these crossings than on those that are built up, but it may be minimized by careful laying. For cross-over roads, it is desirable to have the two crossings (**a** and **a**, *Fig.* 27, *Plate* LXXIV.) of the same angle, otherwise it is difficult to insure easy running, and the crossings come so close together that there is little room for adjustment.

In stations where several sidings fan out from the main line, they should be designed so as to avoid a series of curves. Stations are sometimes improperly laid out, as shown at *Fig.* 29, *Plate* LXXIV., when the proper way would have been as shown at *Fig.* 30; it is a small difference in detail, but it makes a great difference in the wear and tear of shunting.

In laying in points it should always be remembered that the heel of the switch is an obligatory point, for there is a certain distance required for the clearance of the flange of the wheel and the width of the head of the rail, so that the length of the switch is generally shorter than the theoretical length of the true curve drawn through the crossing and the heel of the switch. Practical considerations limit the length of the switch, so that the curve is, as a rule, theoretically incorrect; this is, however, in practice so adjusted that it is not noticeable either to the eye or by any jar to the rolling stock. Sometimes very long switch rails have been tried, but the difficulty of keeping a long unstayed switch rail in proper position has made the remedy worse than the disease.

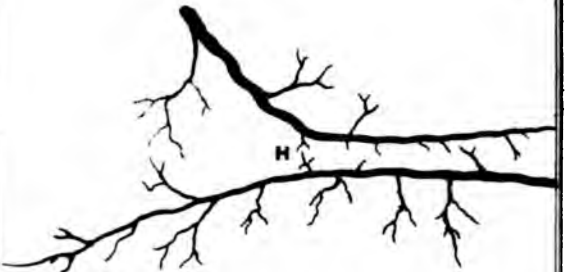
The sections showing the wear of rails, as indicated at the bottom of *Plate* LXXIV., are instructive as showing the manner in which rails wear on a curve; the greater wear is, as a rule, not on the outer, but on the inner rail, owing to the additional weight thrown on to it in consequence of the super-elevation of the outer rail. In those sections which are marked with an asterisk, the wear on the inner rail has exceeded that on the outer rail; in fact, even where the wear of the outer rail has exceeded that of the inner rail, the upper surface of the outer rail has, as a rule, worn down less.

The wear up to a certain point appears to be fairly proportional to the radius, but where it has been allowed to become excessive, as shown in the last of these sections, the rolling action of the tyre is exchanged for a grinding action, which increases the wear very rapidly. It is, however, impossible to distinguish in these sections how much of the wear is due to the curve, and how much to the super-elevation of the outer rail. If the elevation be insufficient for the velocity of the trains, the grinding action on the outer rail will be considerable; but if the super-elevation be greater than necessary for the speed, the wear on the inner rail will be increased. The wear round curves must, however, depend greatly on the length of rigid wheel-base of the rolling stock. Curves of 100 feet radius have been used with bogie stock on the New York Elevated Railway at portions where it is necessary to proceed at a slow speed, but curves of a smaller radius than 600 feet are very undesirable, and unless great saving is to be obtained in a mountainous country it is better not to adopt curves of less than 1,000 feet radius. In a hot, dry climate, the wear on curves will necessarily be greater than in a cool, moist climate.

TRUCTION. PLATE I.

5

8^{a}



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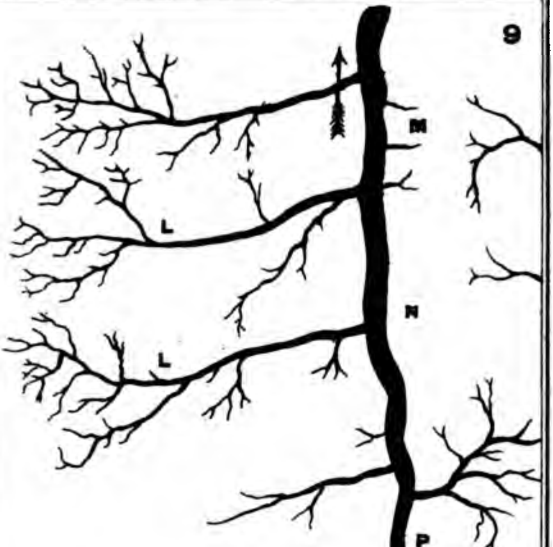

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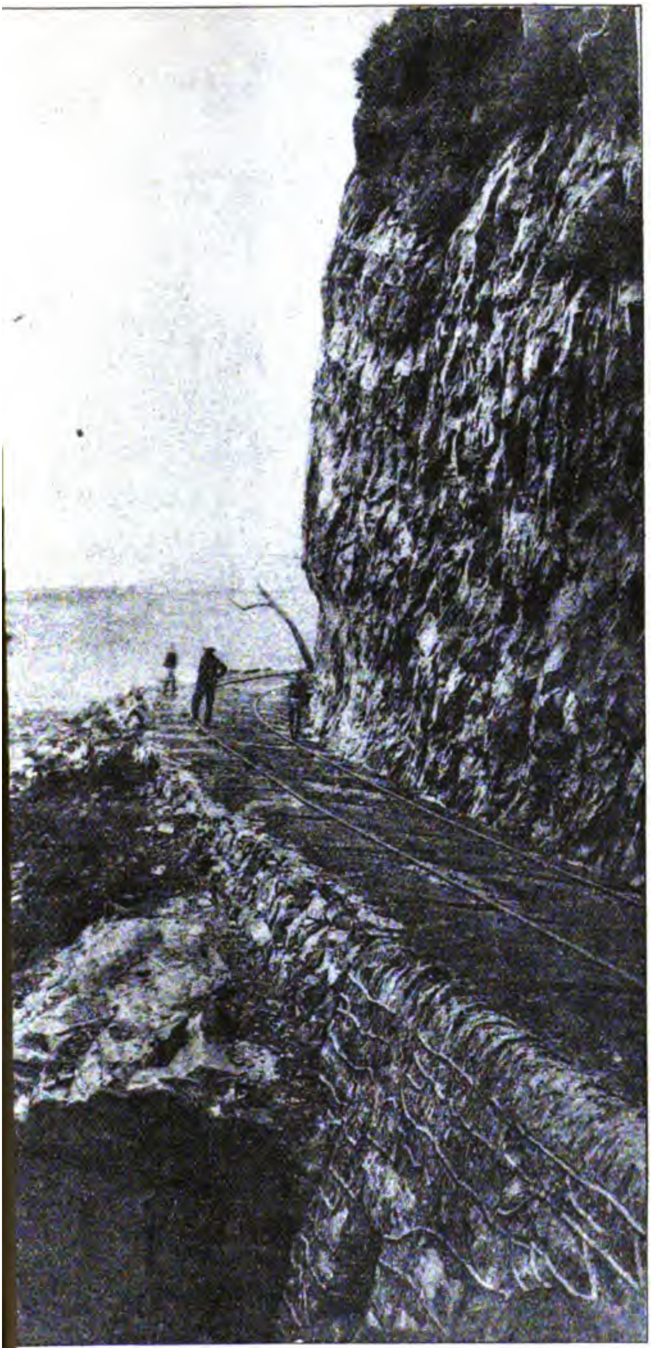
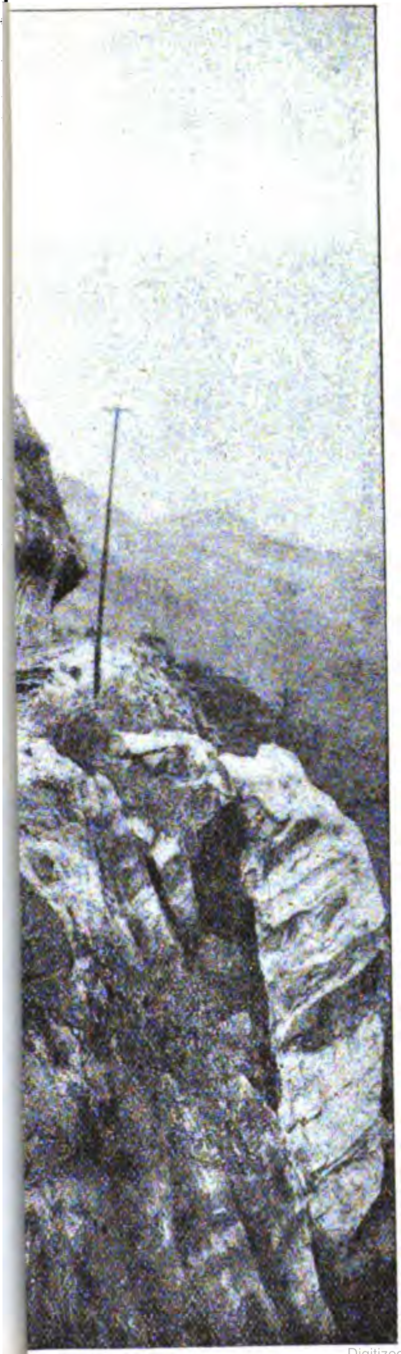
9^{a}



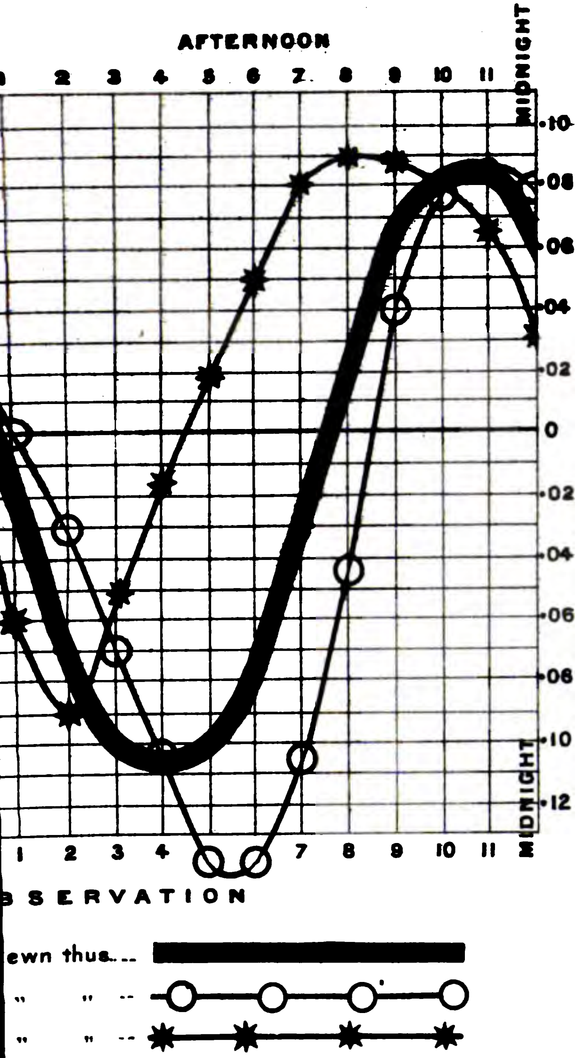


CONSTRUC PLATE IV.

RUCTION.

PLATE V.

FOR DIURNAL WAVE.



RUCTION.

PLATE VI.

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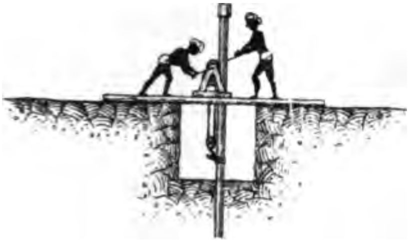

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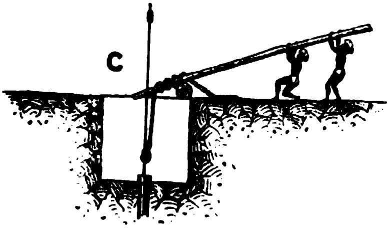


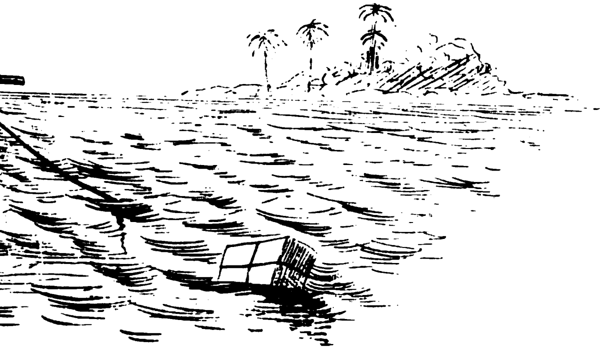
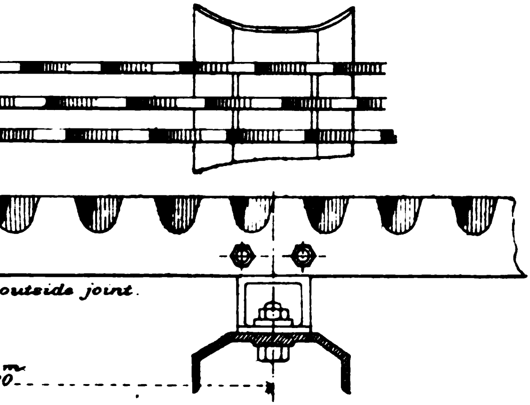


PLATE VII.

PACING OF THE TEETH FIG. Nº 3.



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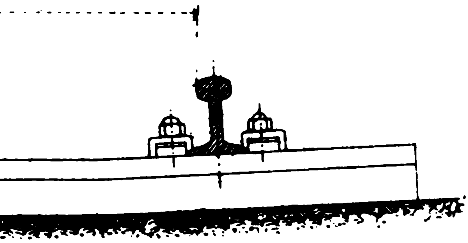

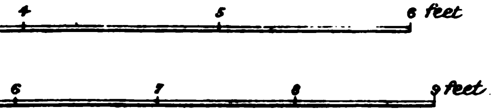

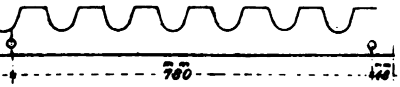

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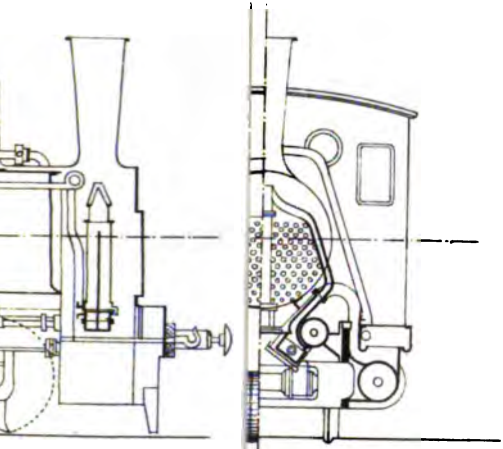
PLATE VIII.

STEM .
COMOTIVE .

TION FIG. N° 9.



NION FIG. N° 10.
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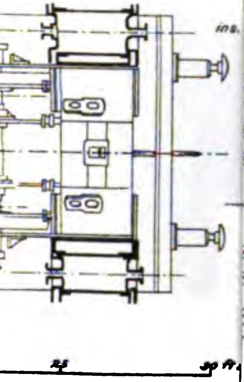

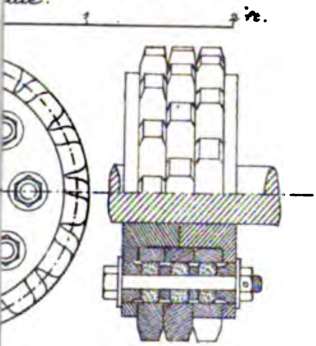

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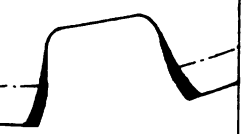


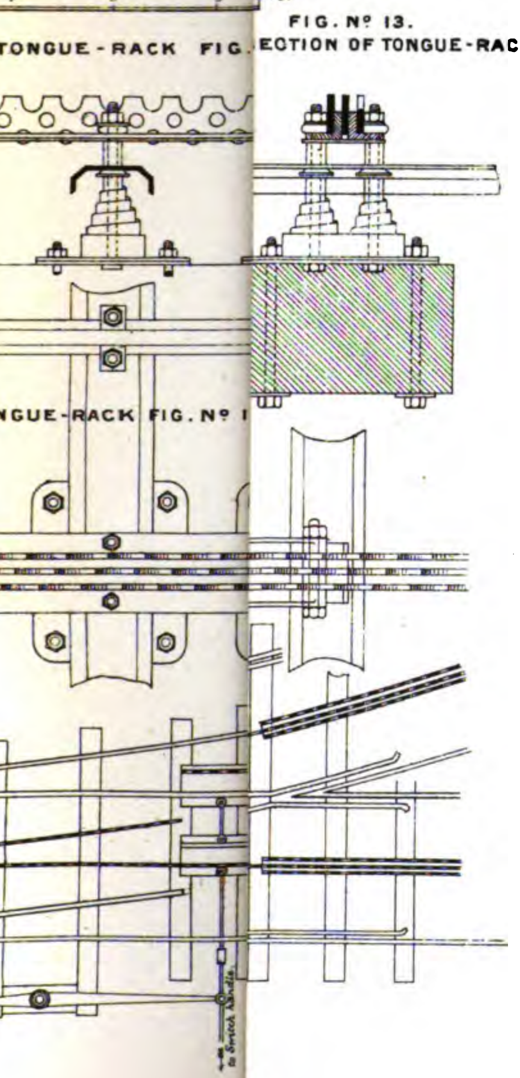
PLATE IX.

CONSTRUC

T SYSTEM.

AND ARRANGEME

for Tongue-rack.



CONSTRUC

PLATE X.

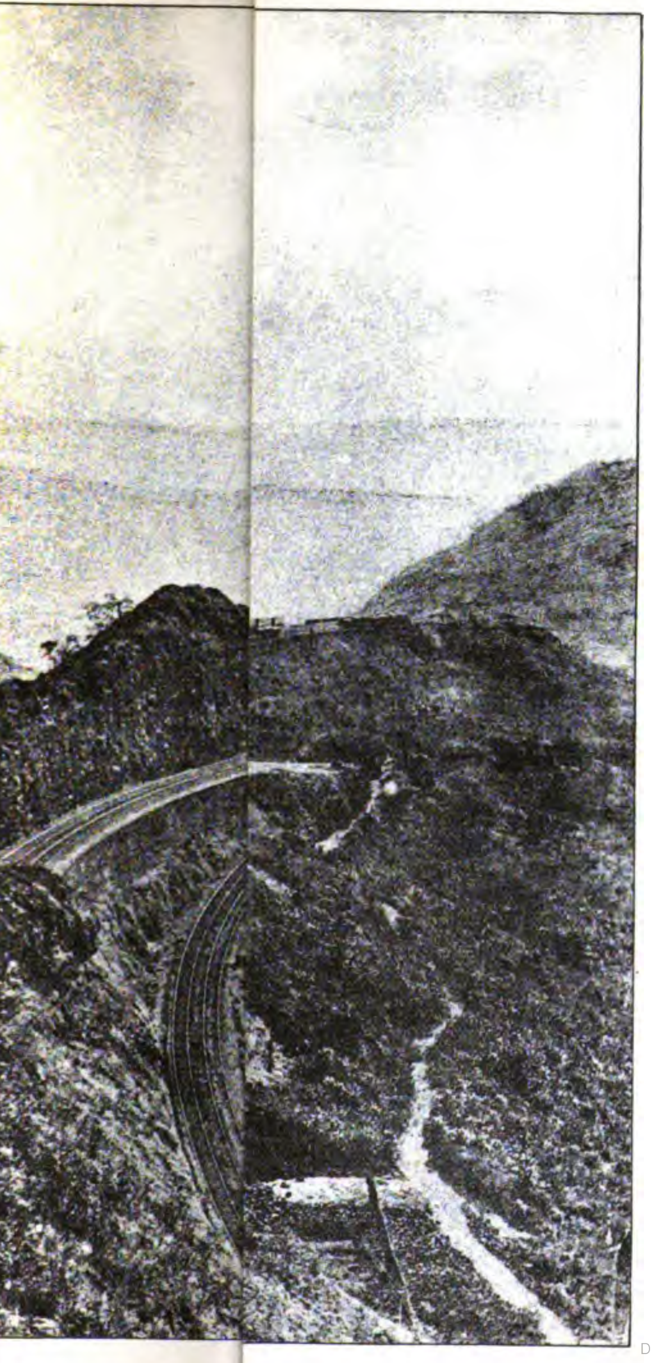


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PLATE XI.

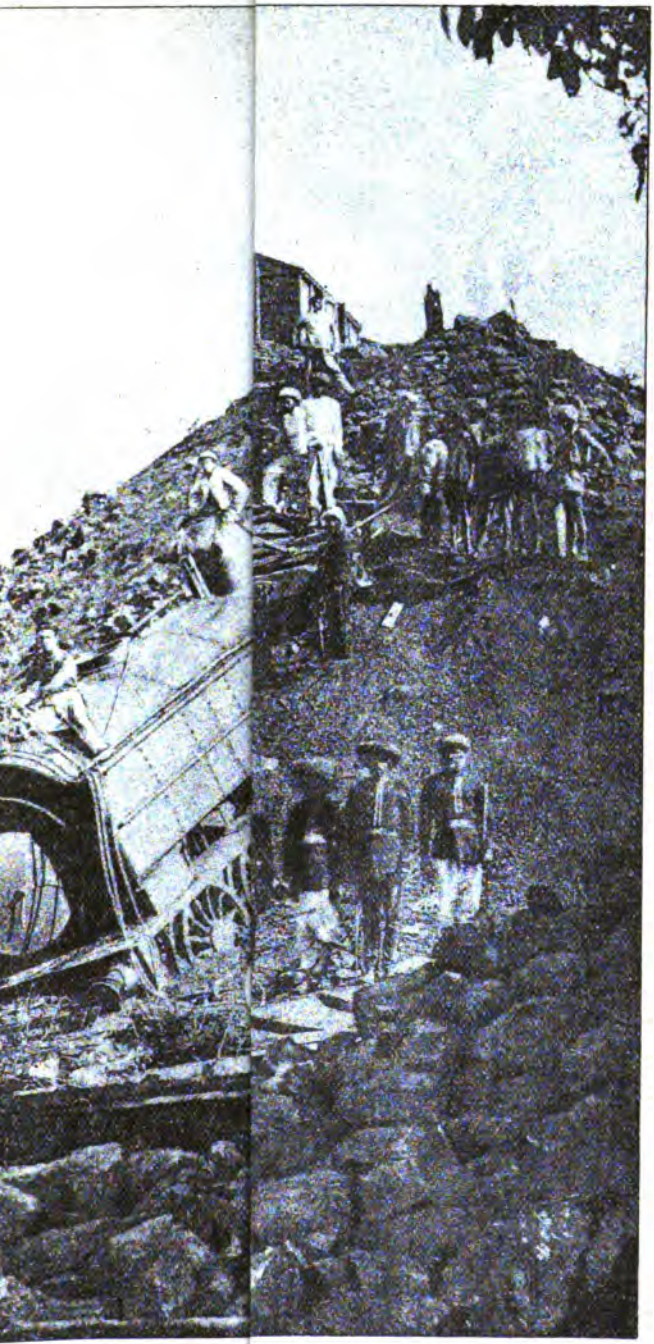

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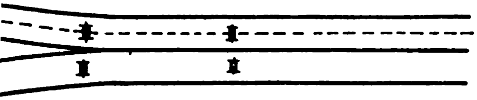
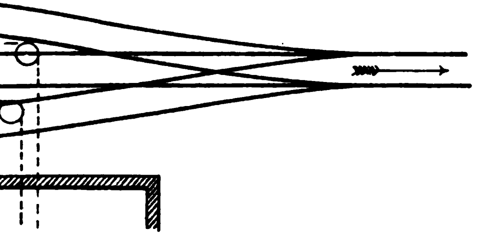
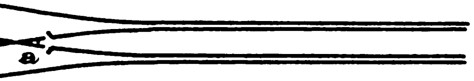
PLATE XII.







Detail at a.

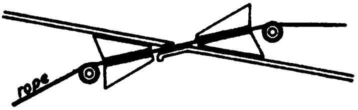


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PLATE XIII.

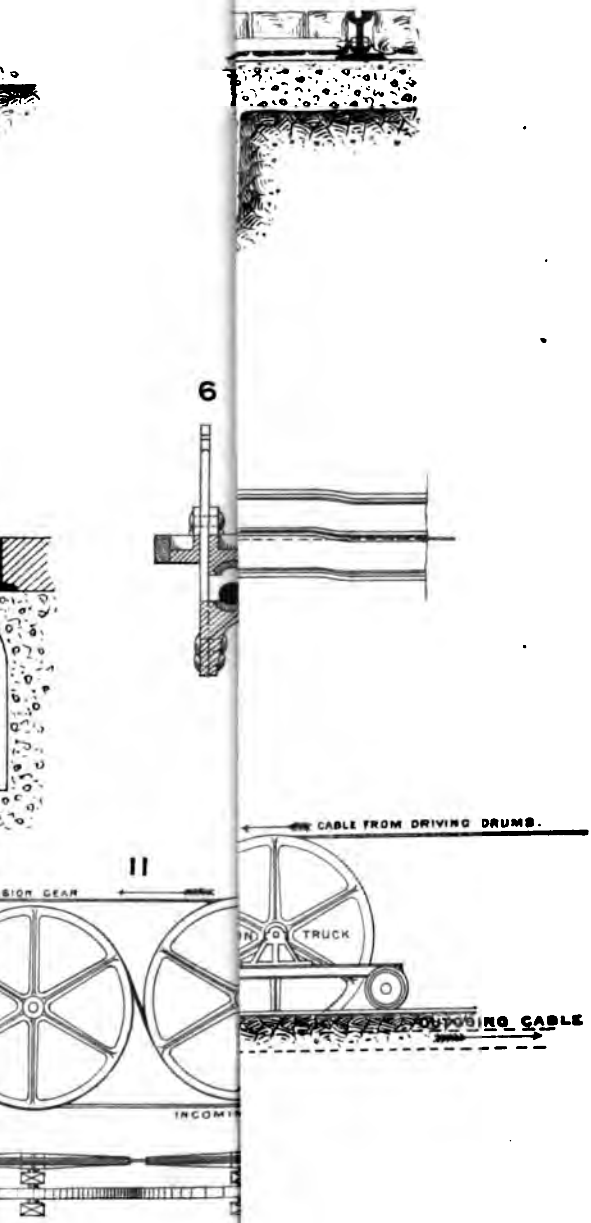

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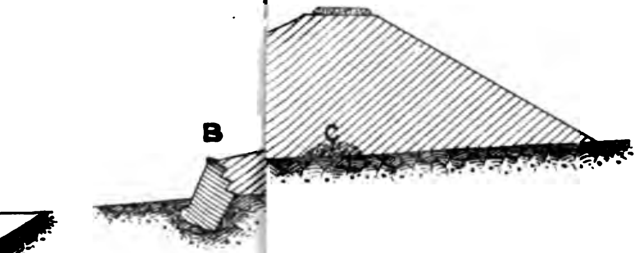
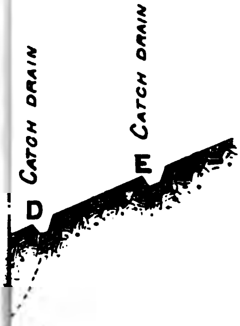
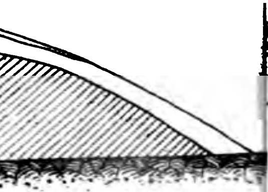
PLATE XIV.



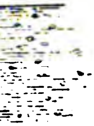




CTION. PLATE XV.

Y CONST

PLATE XVI.



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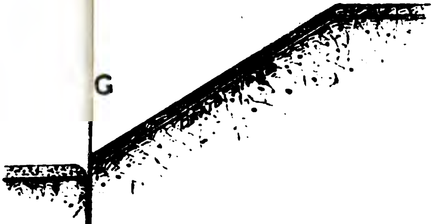

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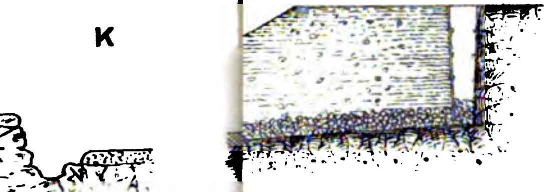

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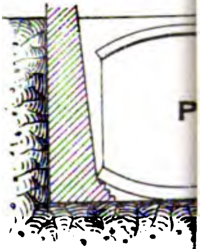

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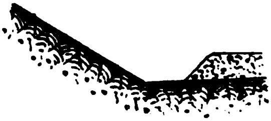

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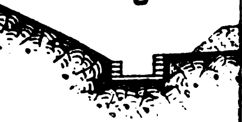

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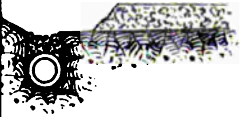

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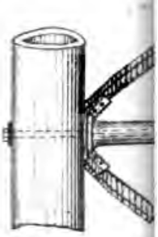
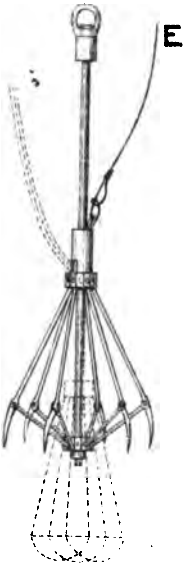
PLATE XVIII.





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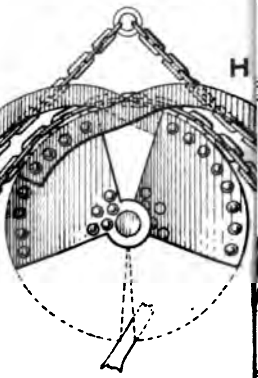

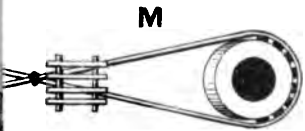

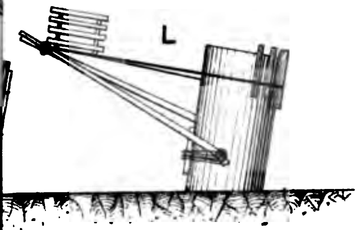

PLATE XIX.

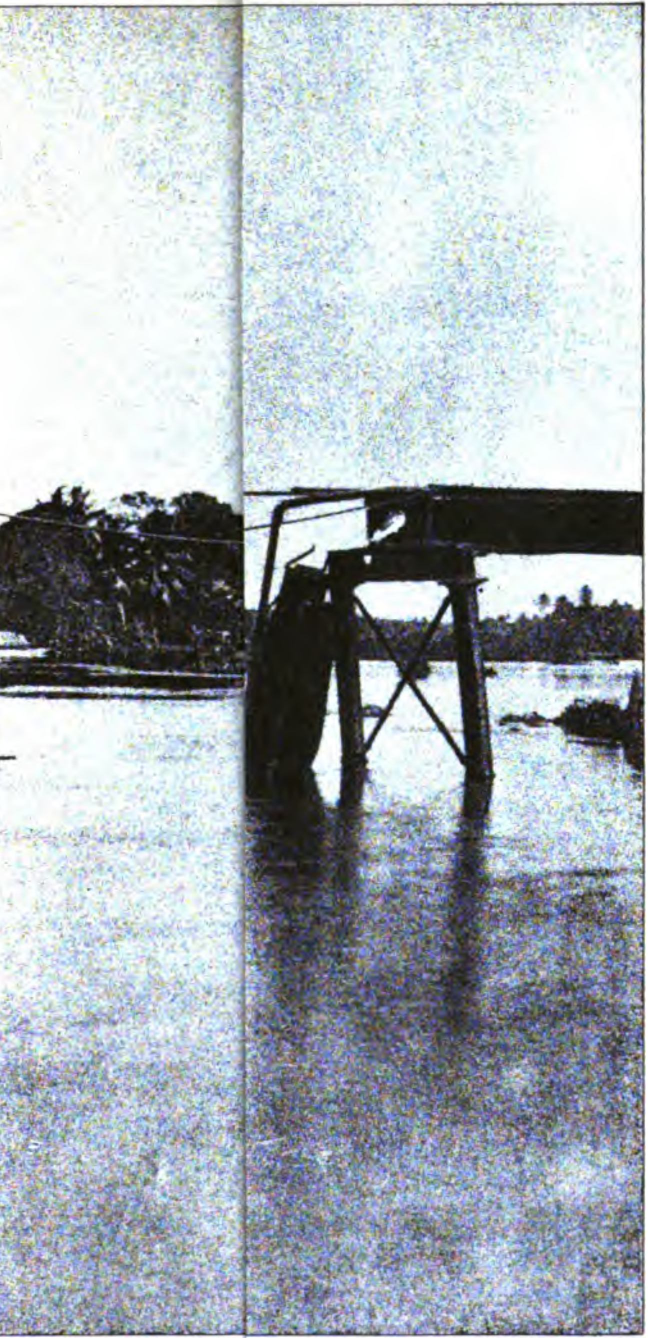

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PLATE XX.

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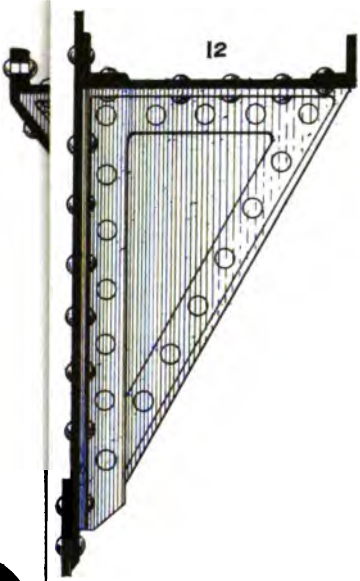

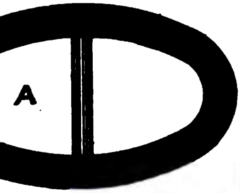

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PLATE XXI.

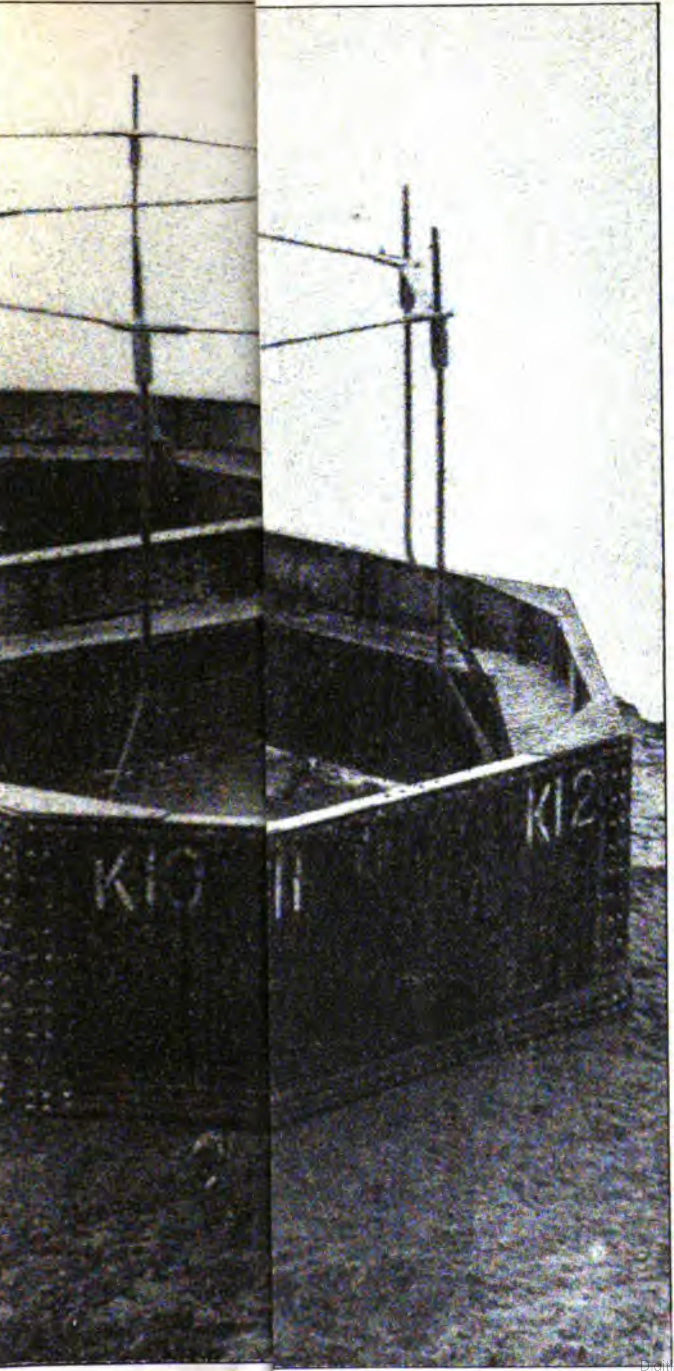

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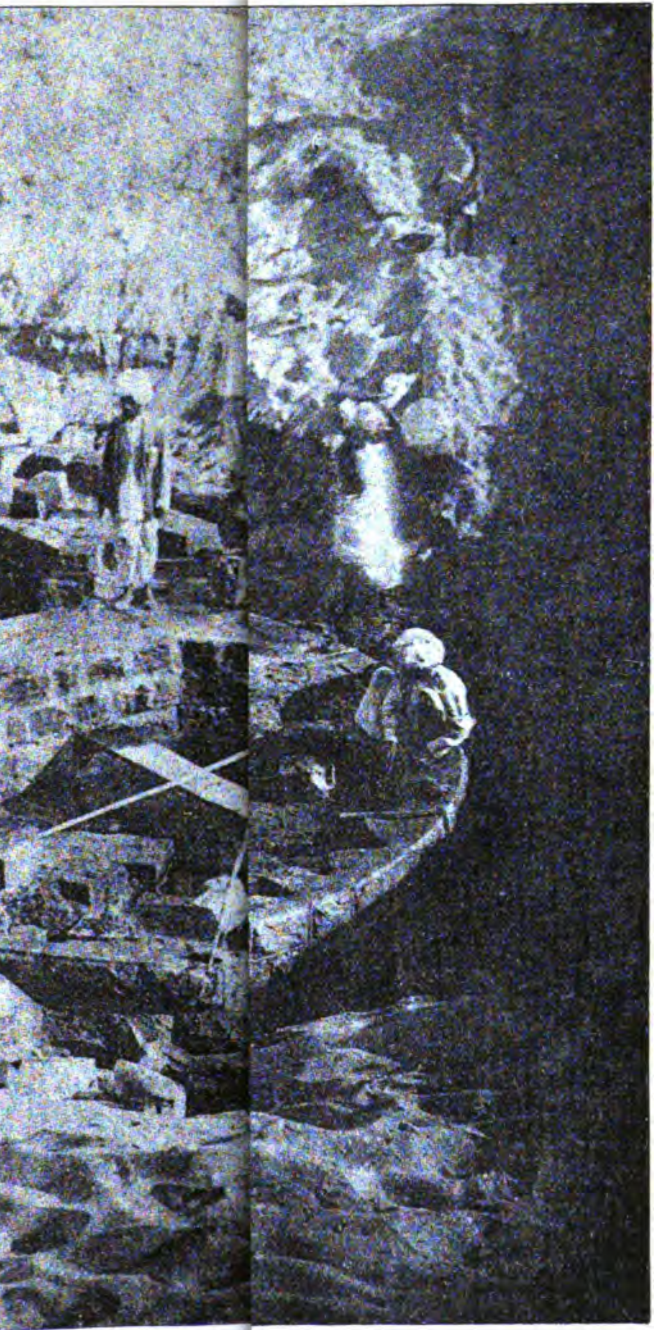
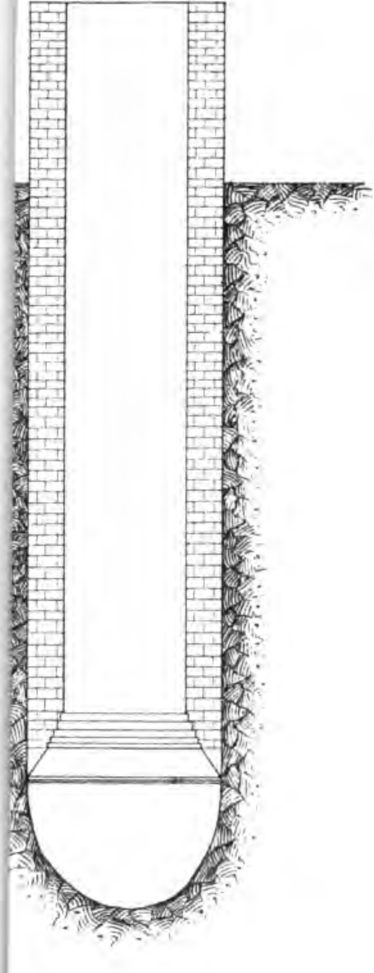
PLATE XXII.





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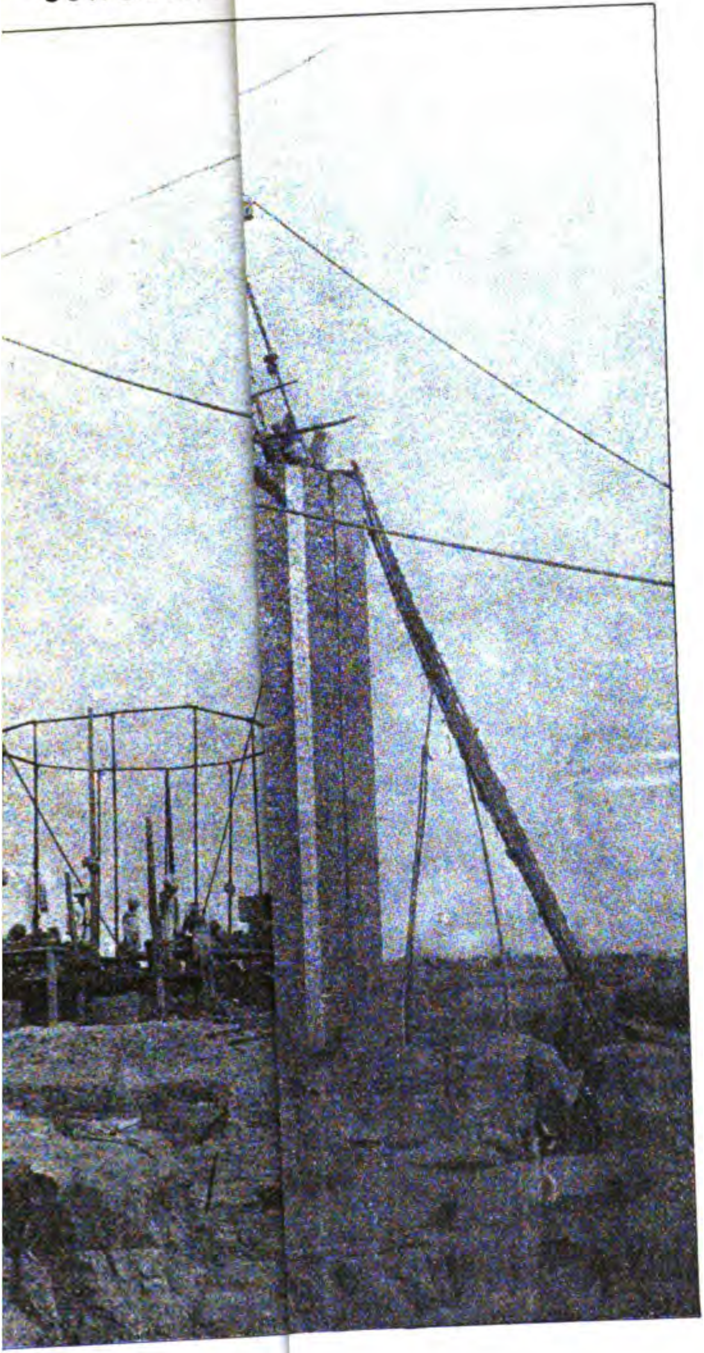

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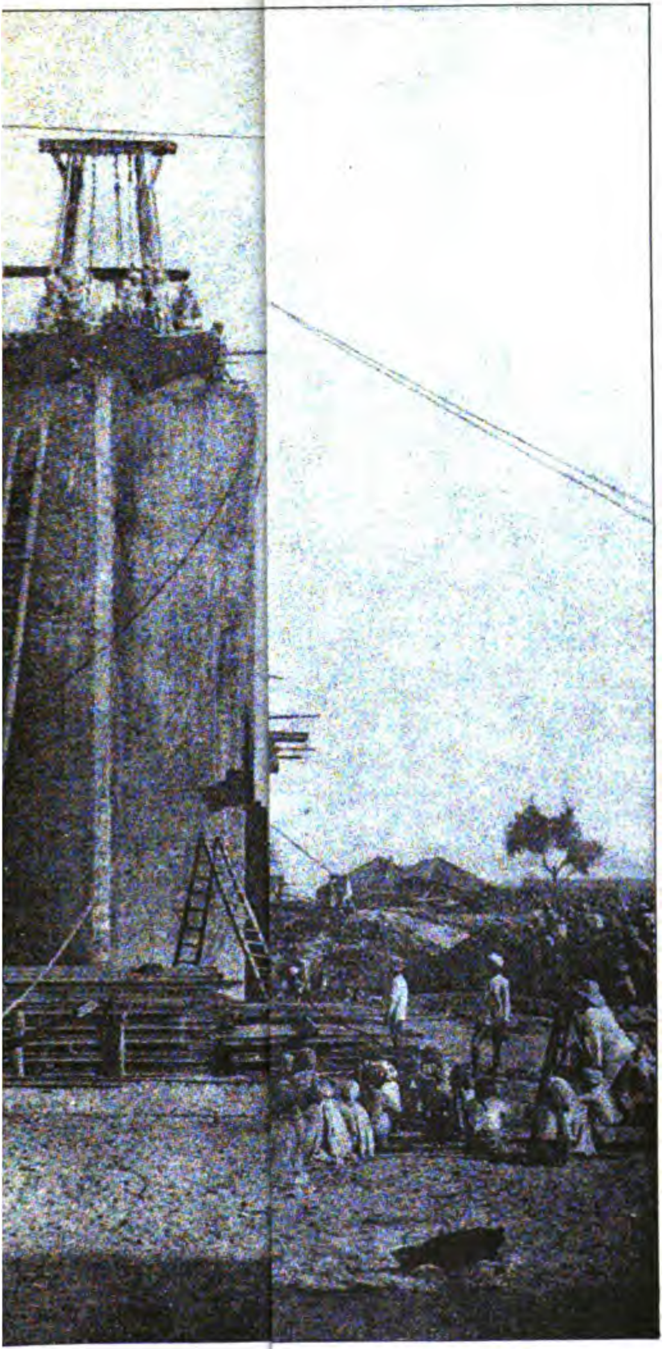

PLATE XXVI.

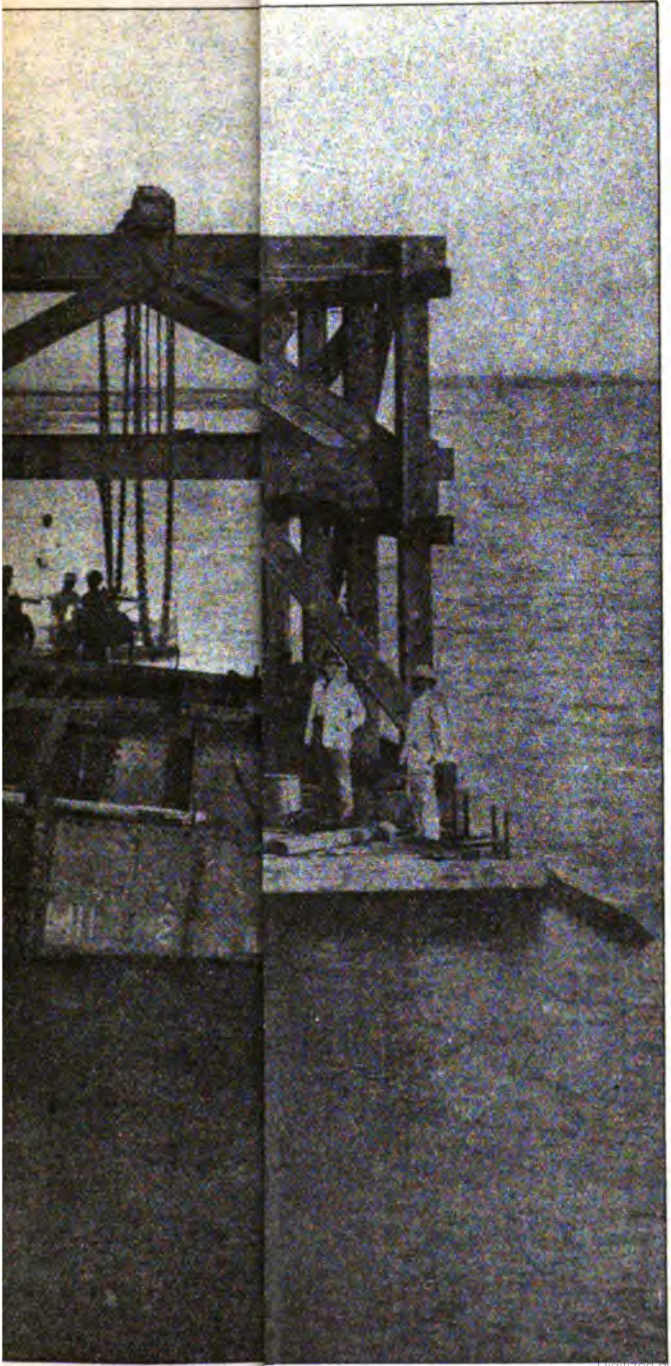

PLATE XXVII.

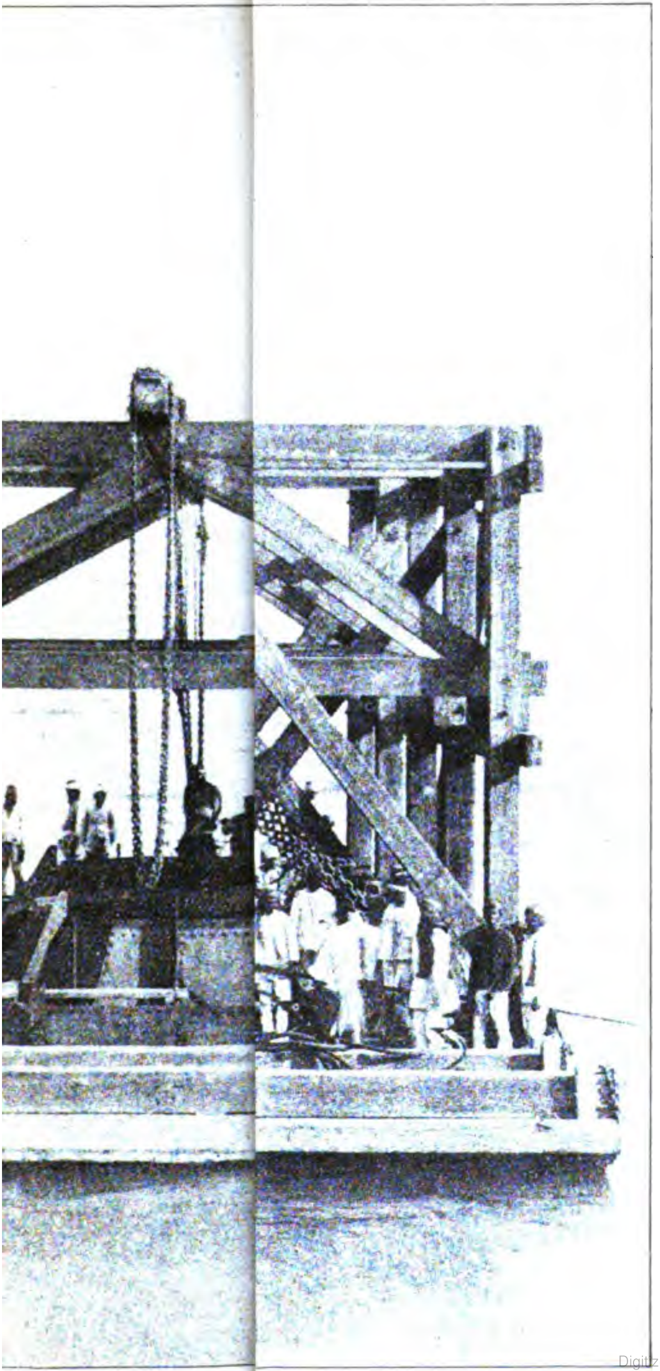

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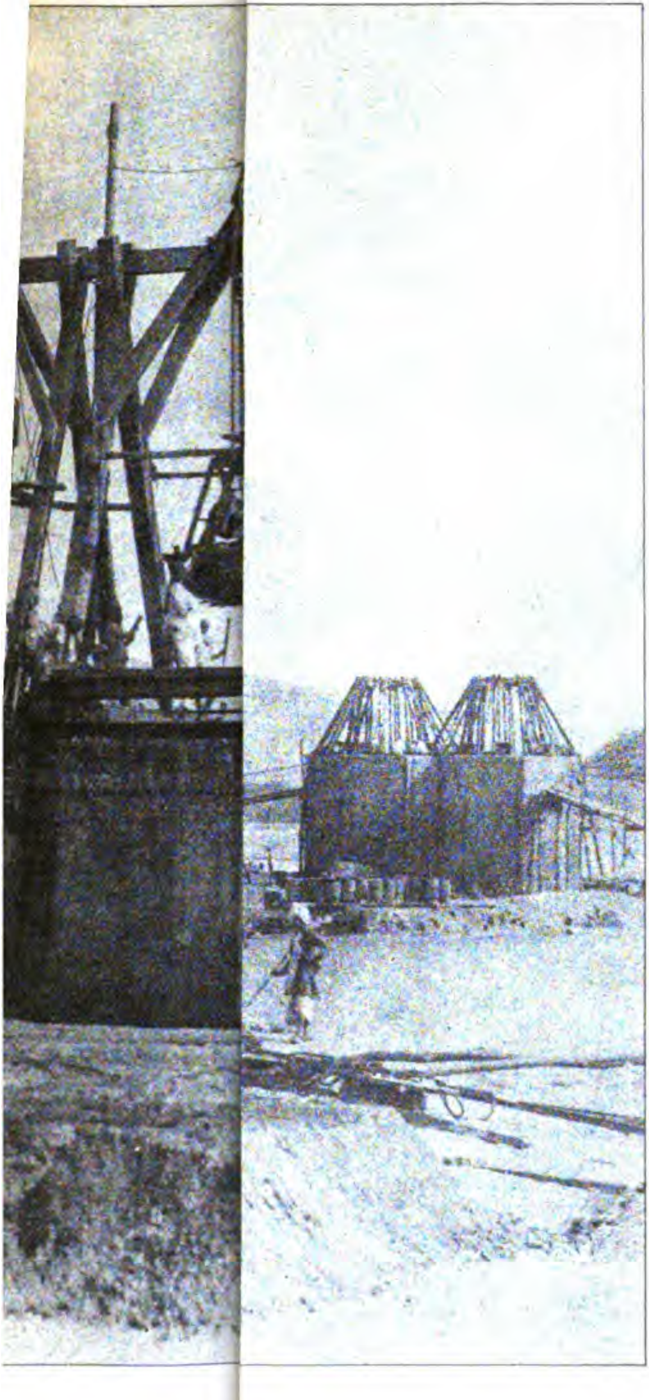
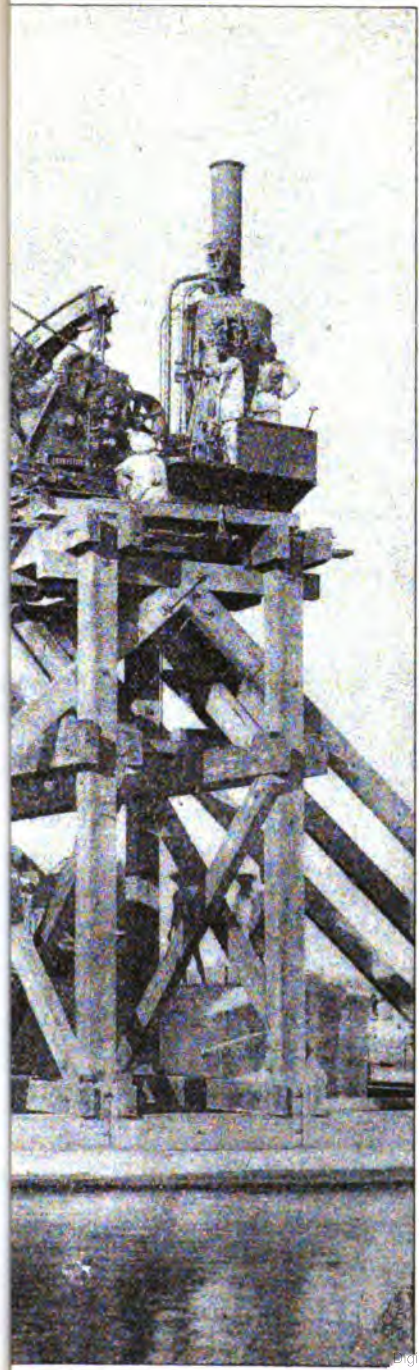
PLATE XXVIII.





CONSTRU

PLATE XXX.

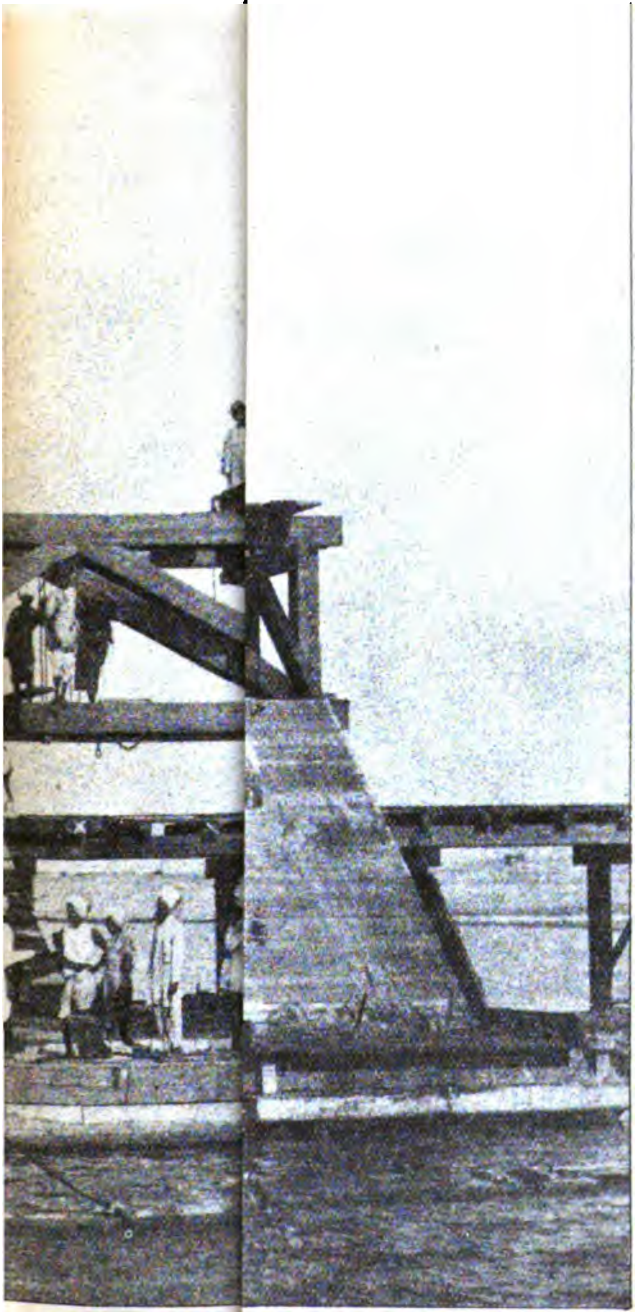


PLATE XXXI.

PLATE XXXII.

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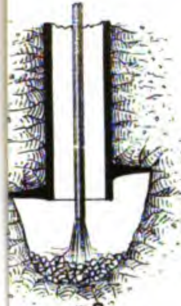

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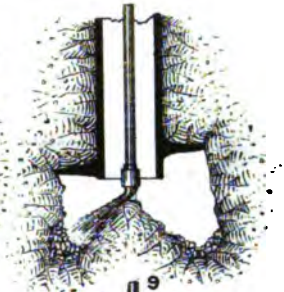

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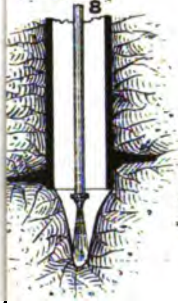

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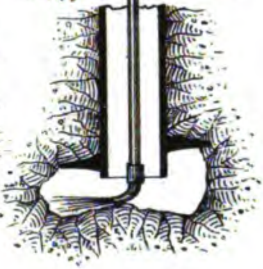

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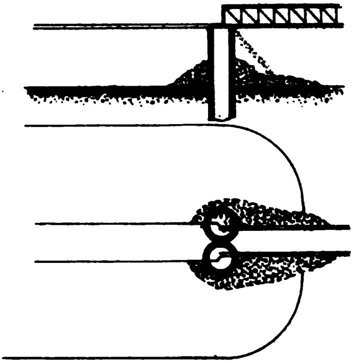
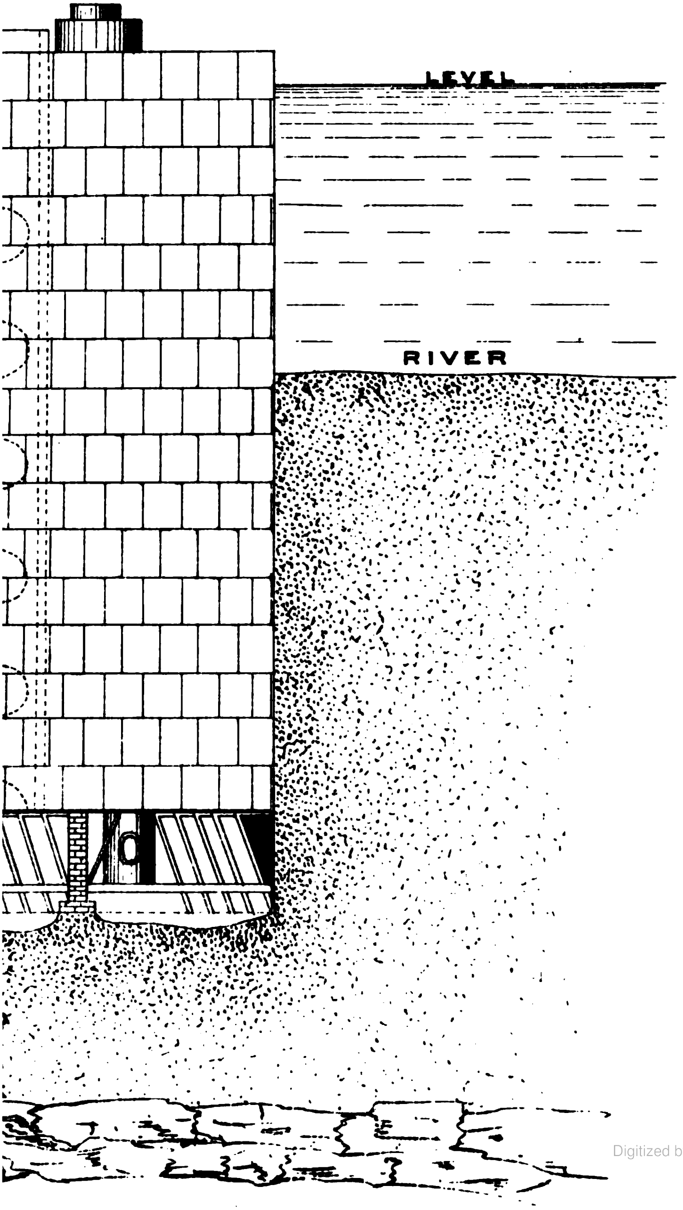


STRUCTION . PLATE XXXIII.



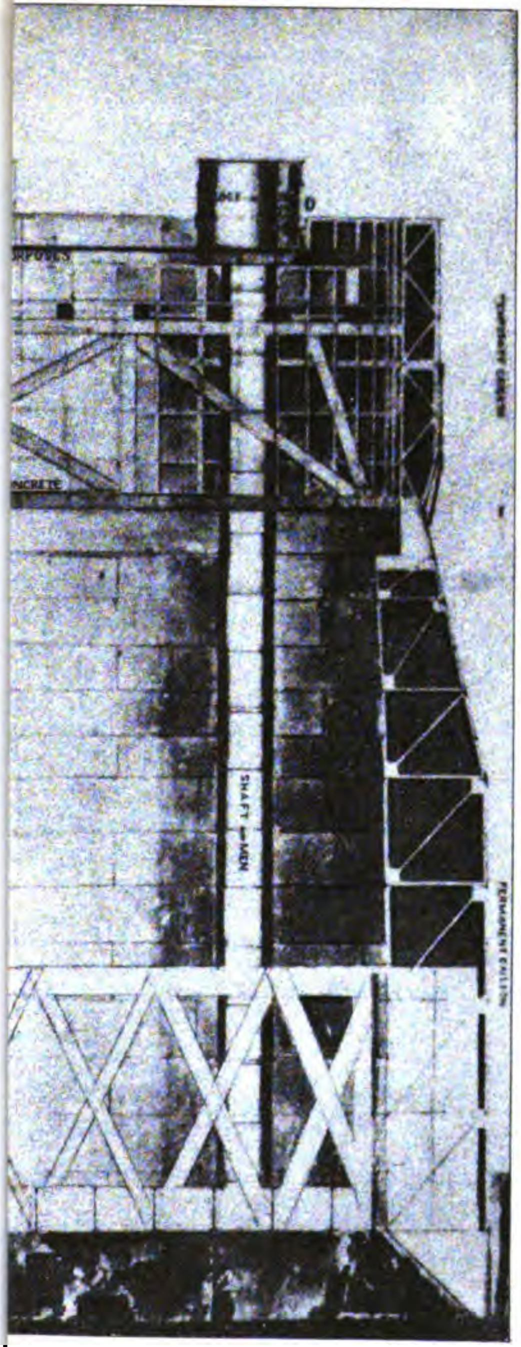

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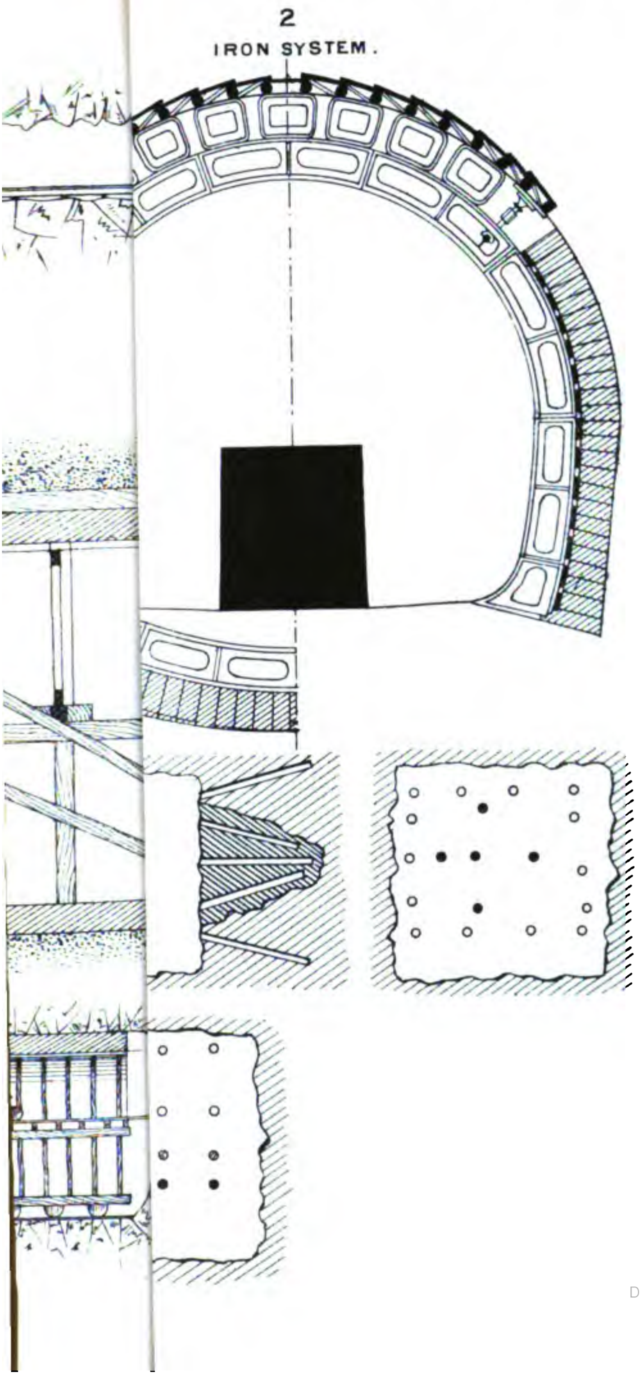
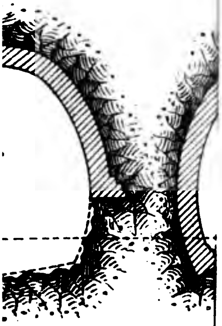
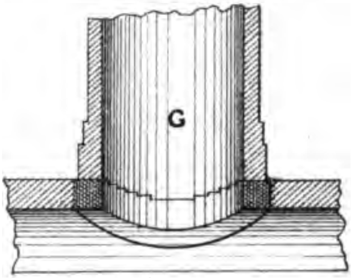
PLATE XXXV.

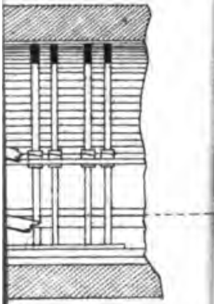


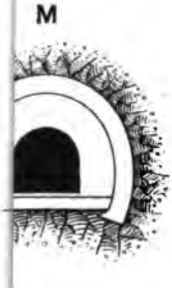
RAIL

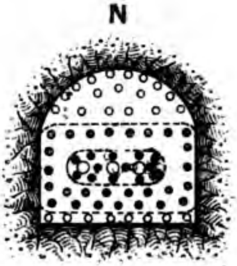
PLATE XXXVI.











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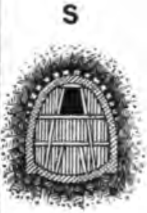

RAILWAY C

PLATE XXXVII.

PLATE XXXVIII.

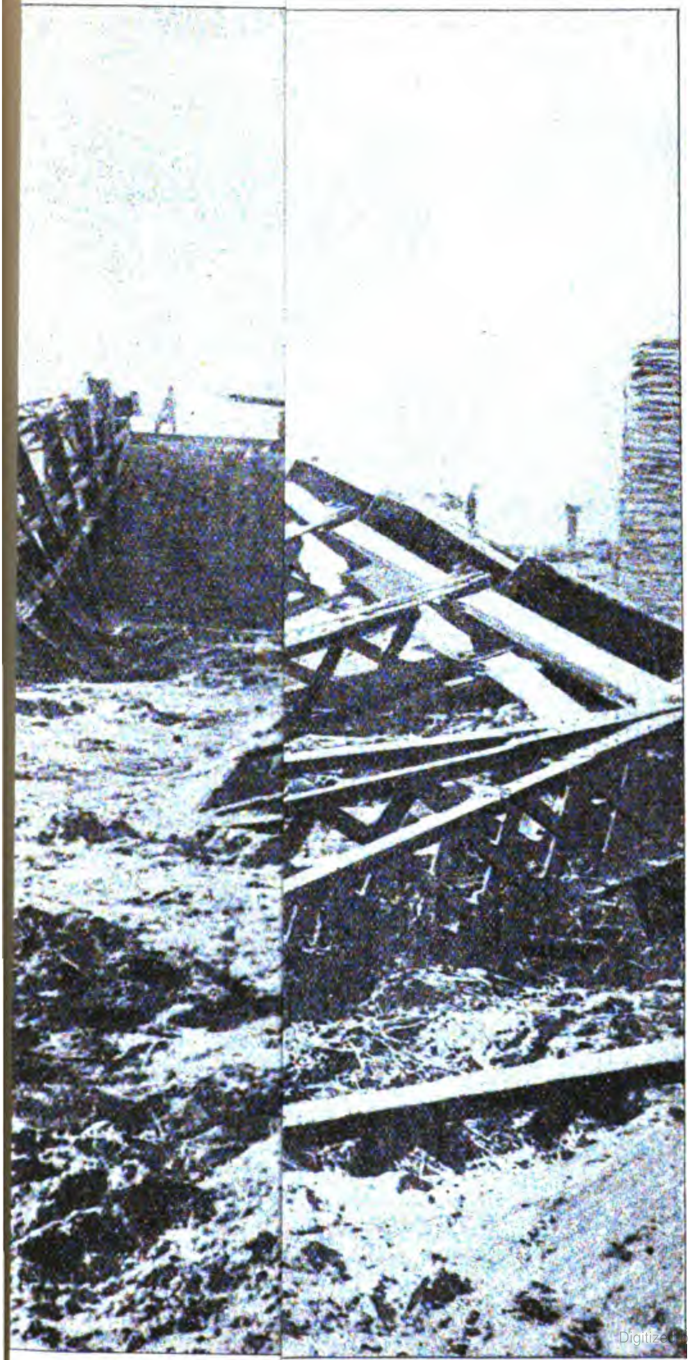

PLATE XXXIX.

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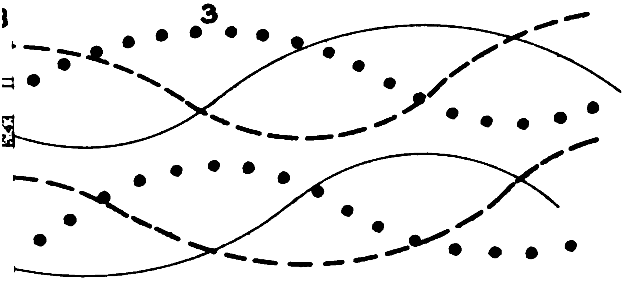

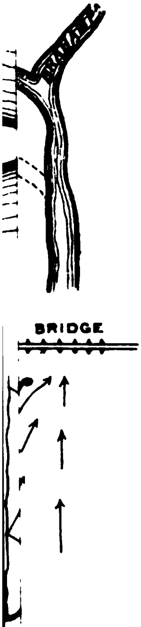

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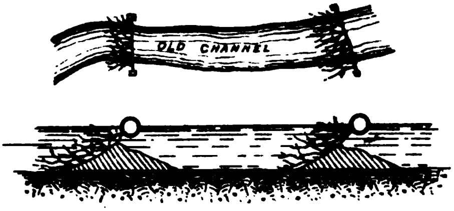

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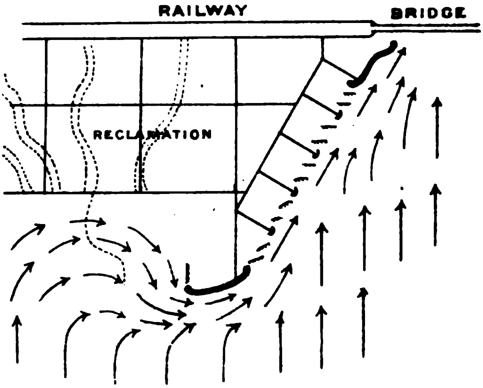

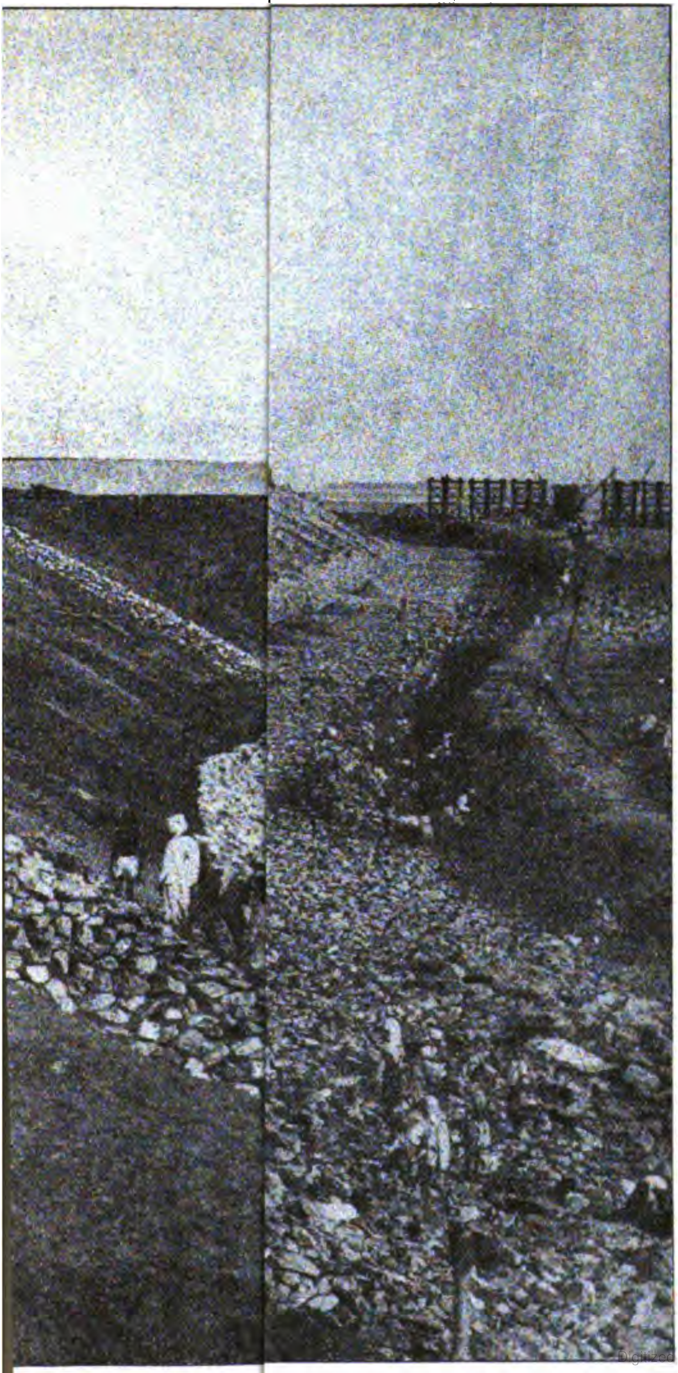

PLATE XLI.

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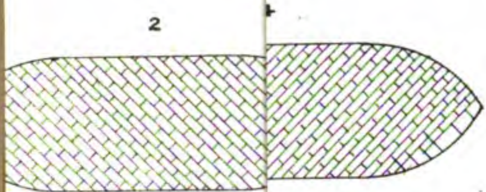

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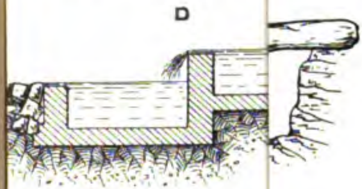

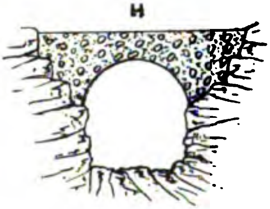

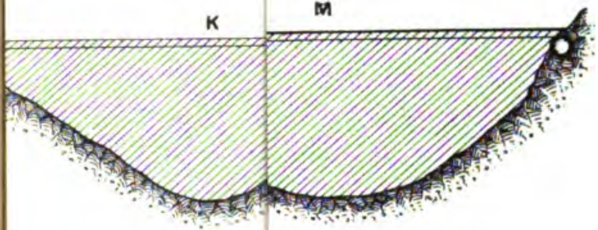

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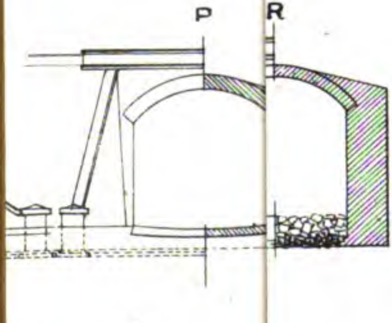

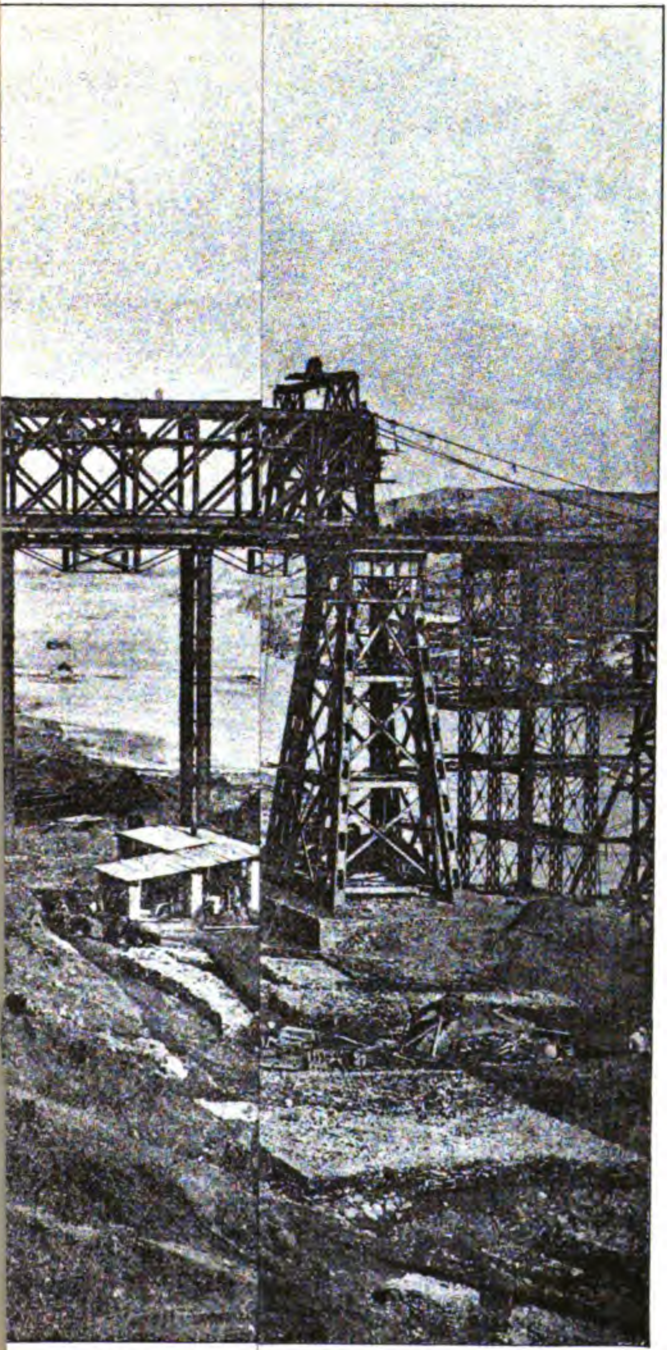

PLATE XLIV.

WAY C

PLATE XLV.

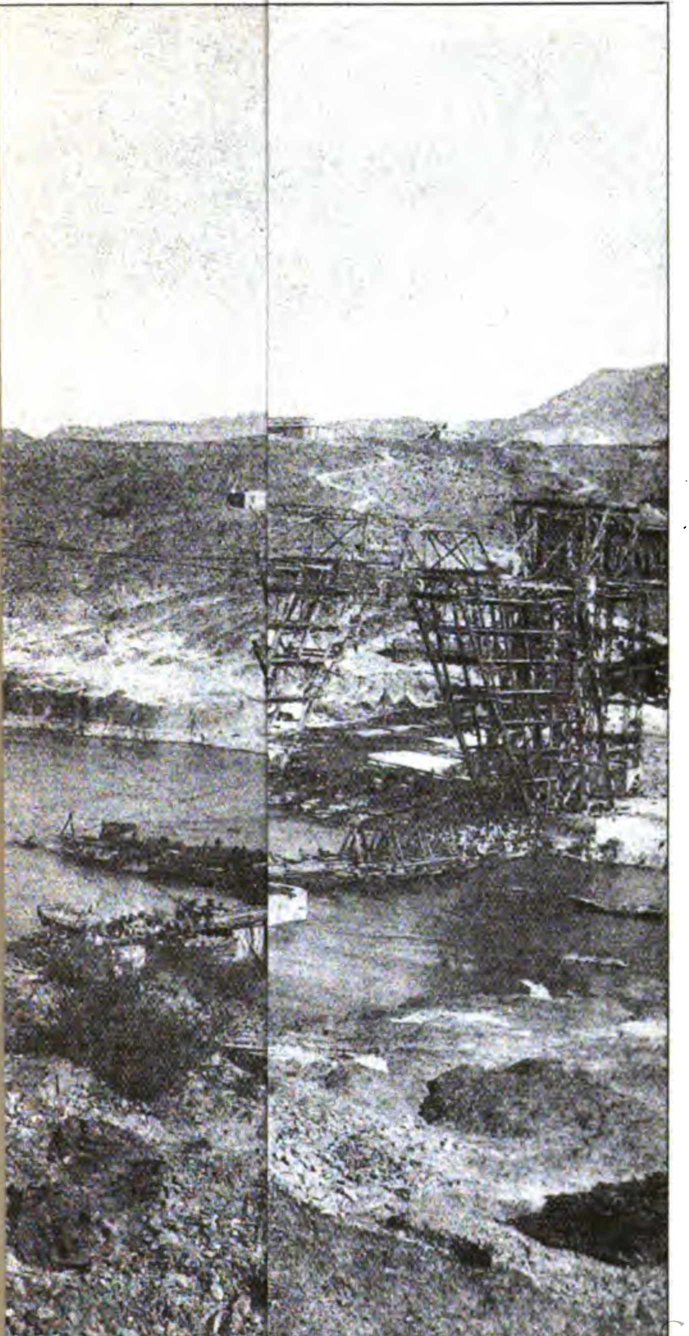

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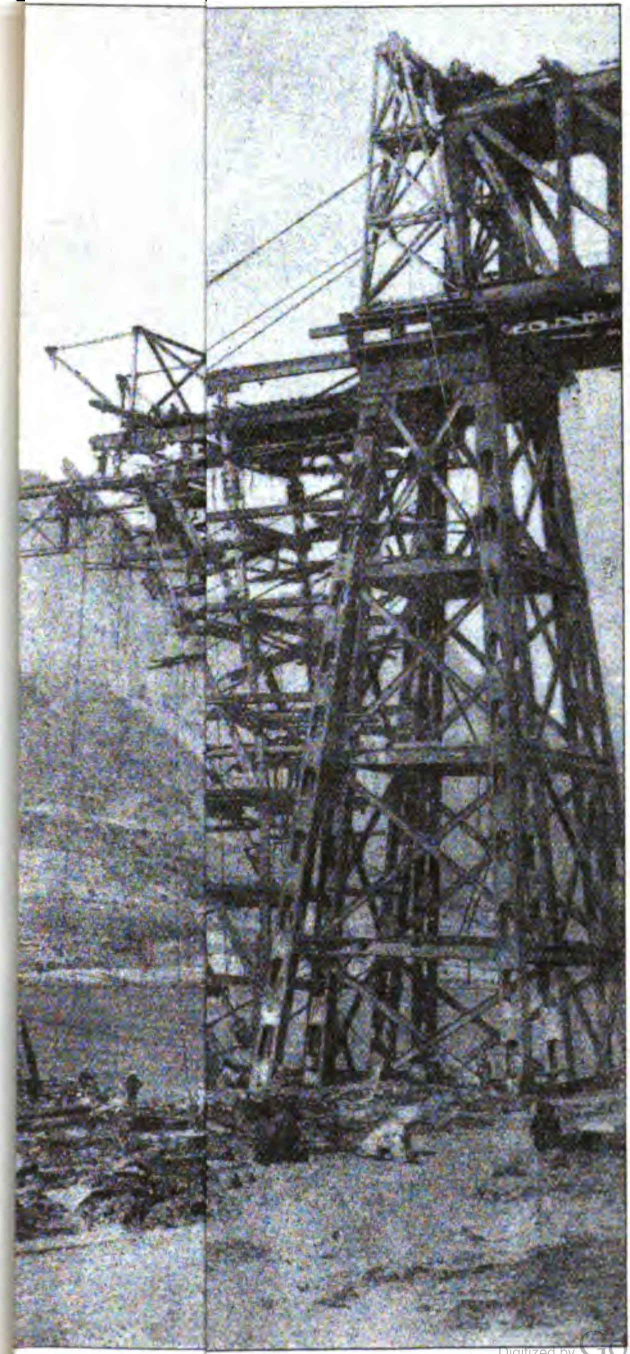
PLATE XLVII.



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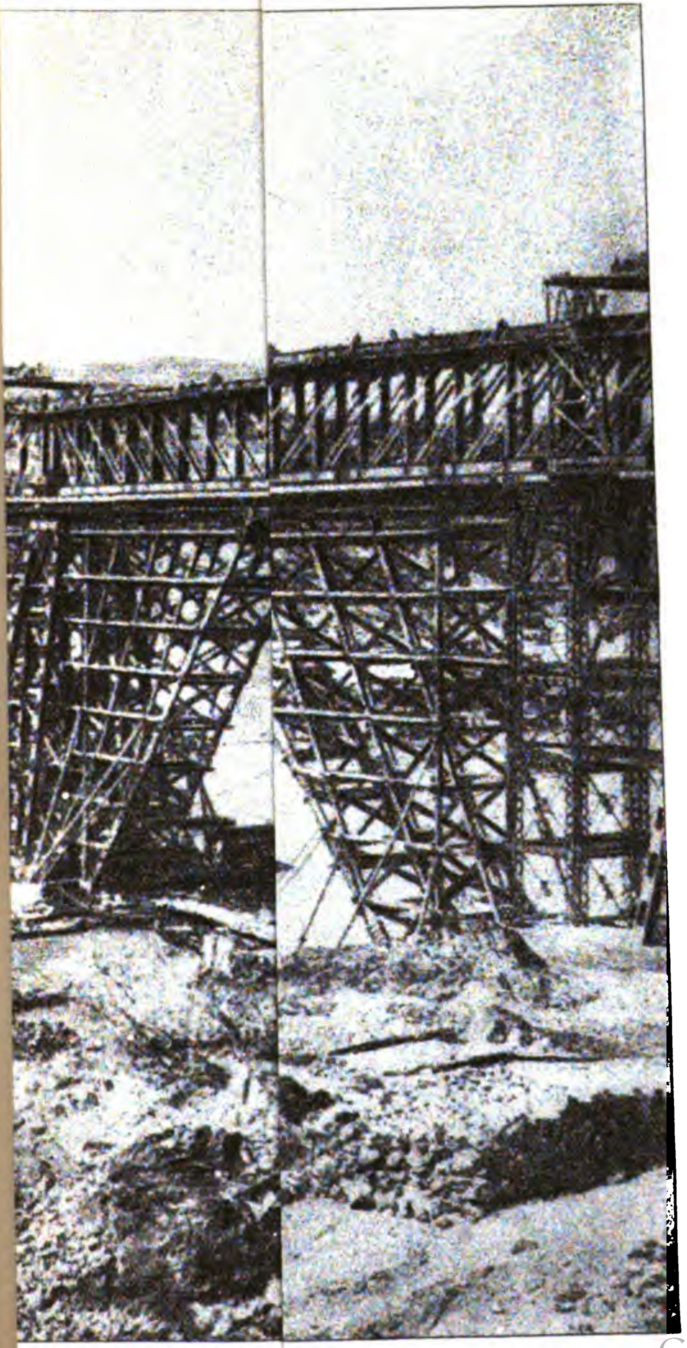

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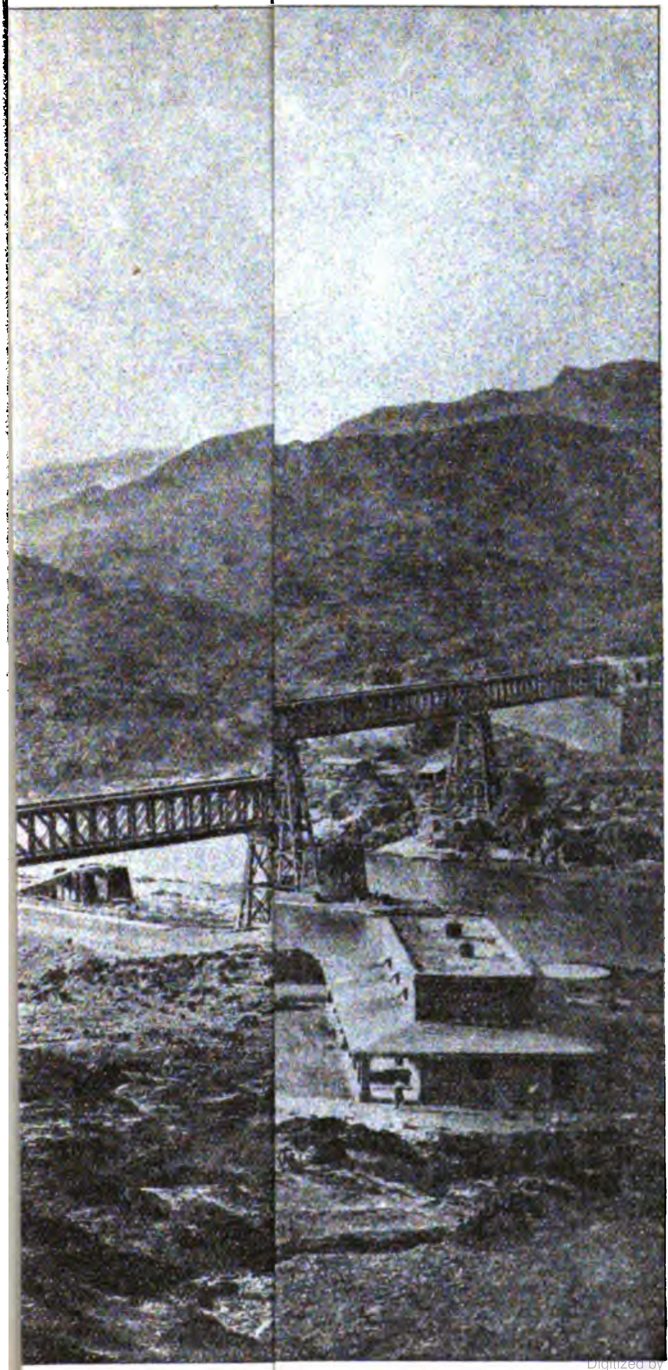

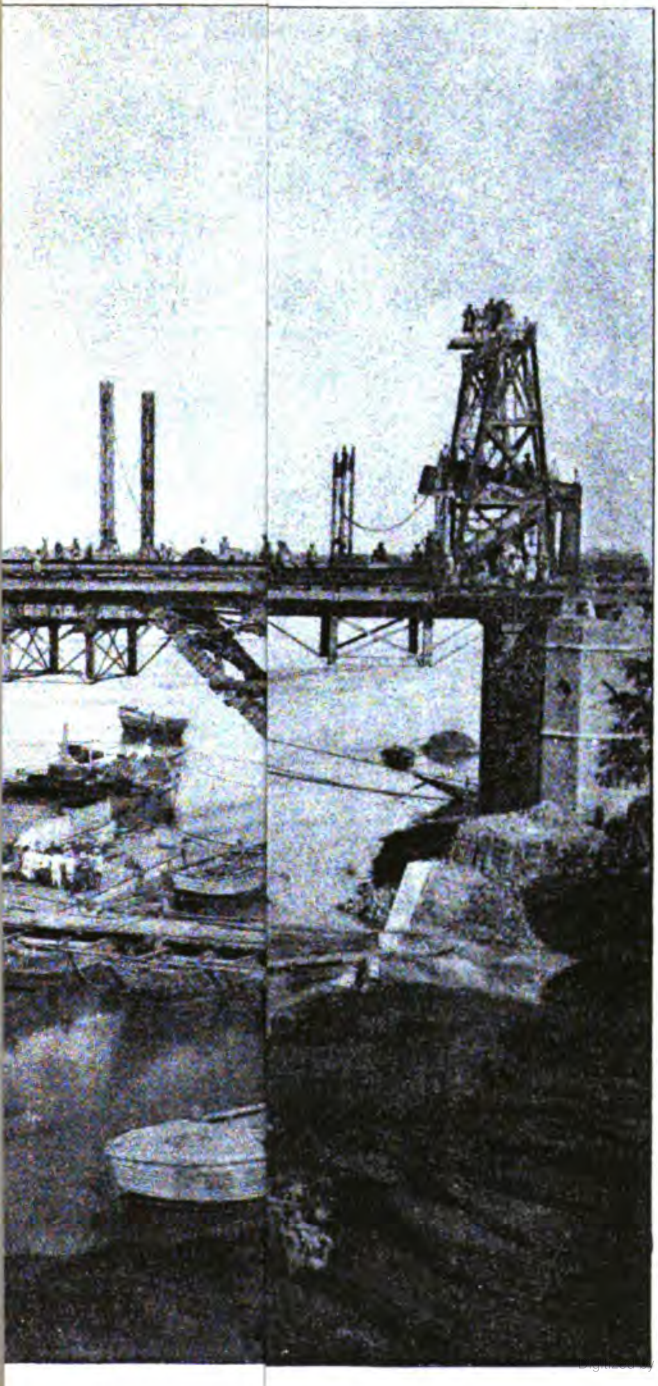

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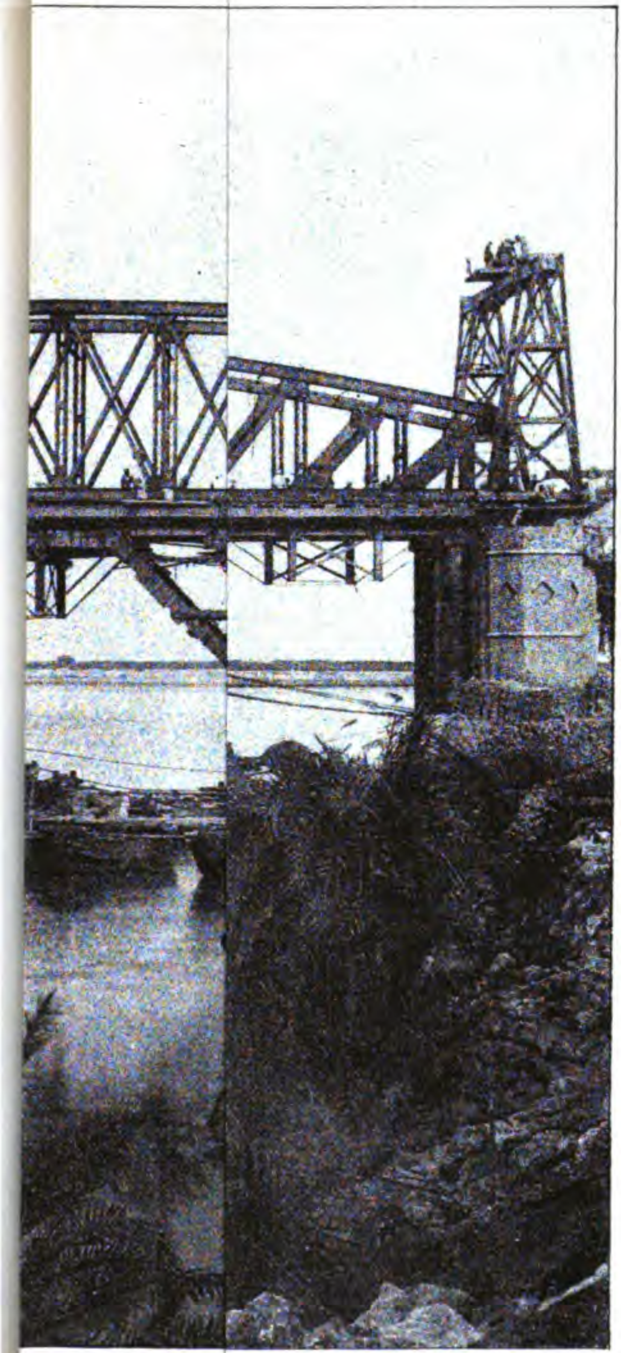

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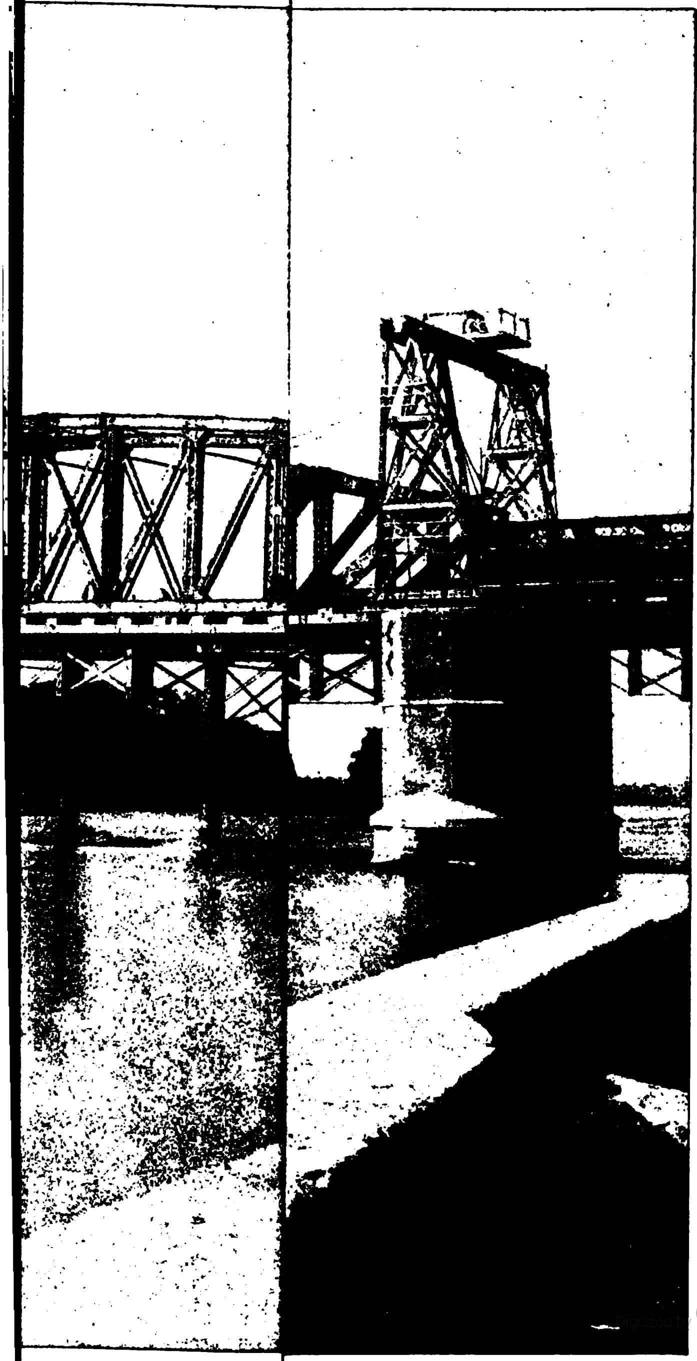

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PLATE LIII.

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PLATE LV.

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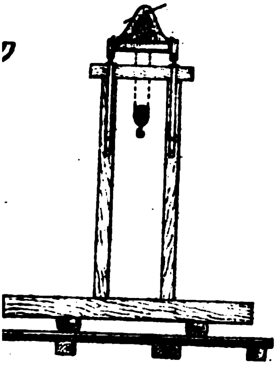

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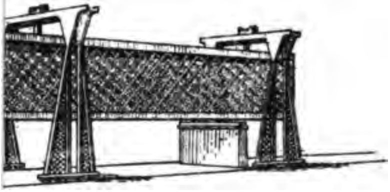

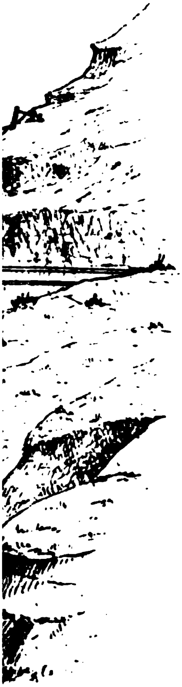

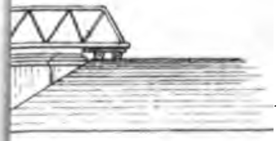

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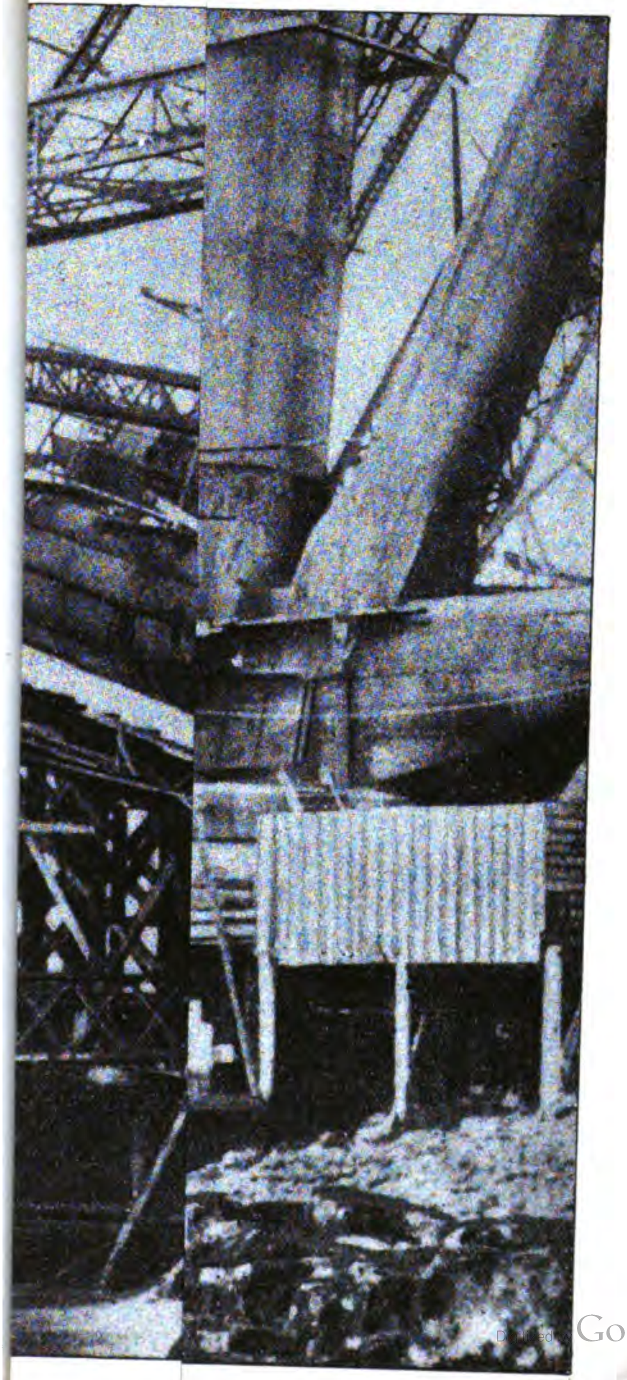

TRUCTION. PLATE LVIII.

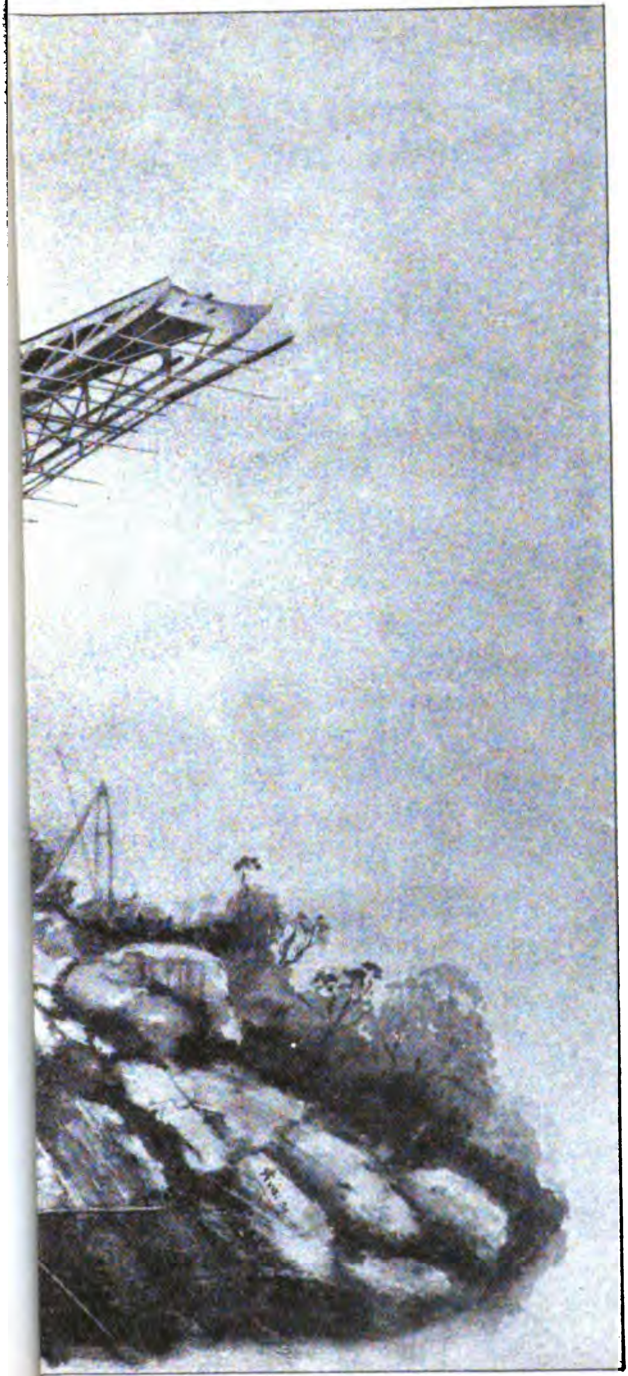

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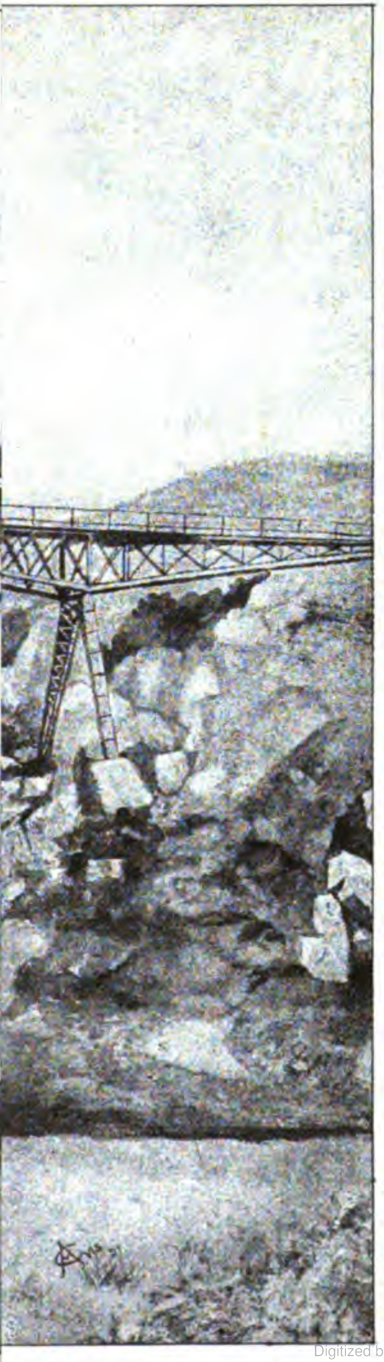
PLATE LX.



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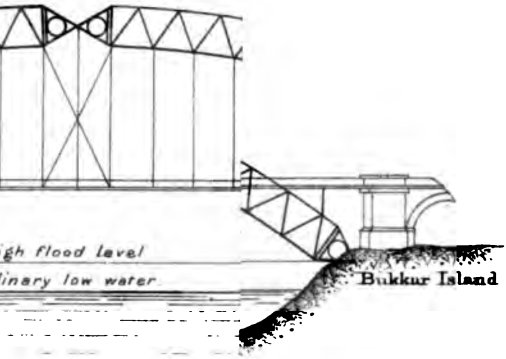

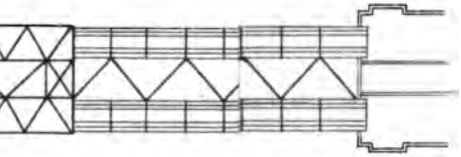

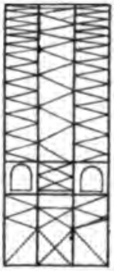

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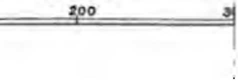

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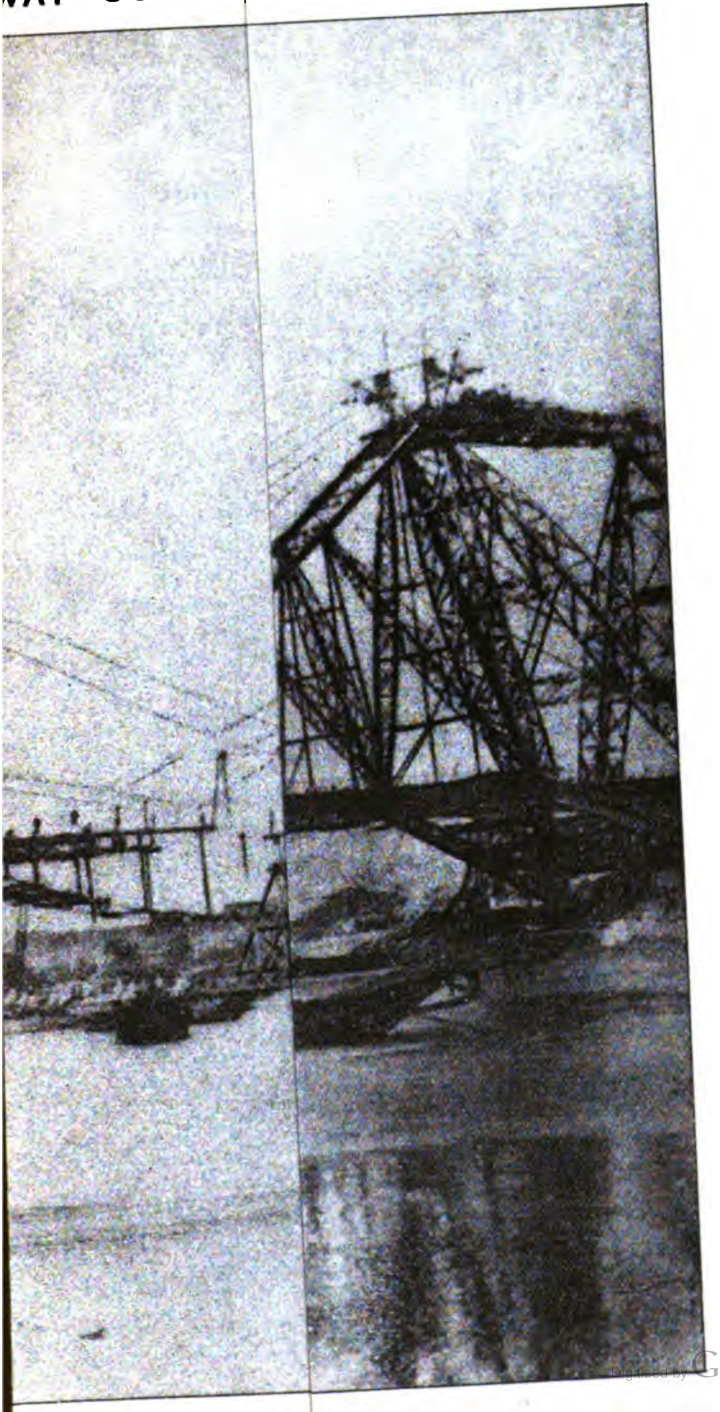

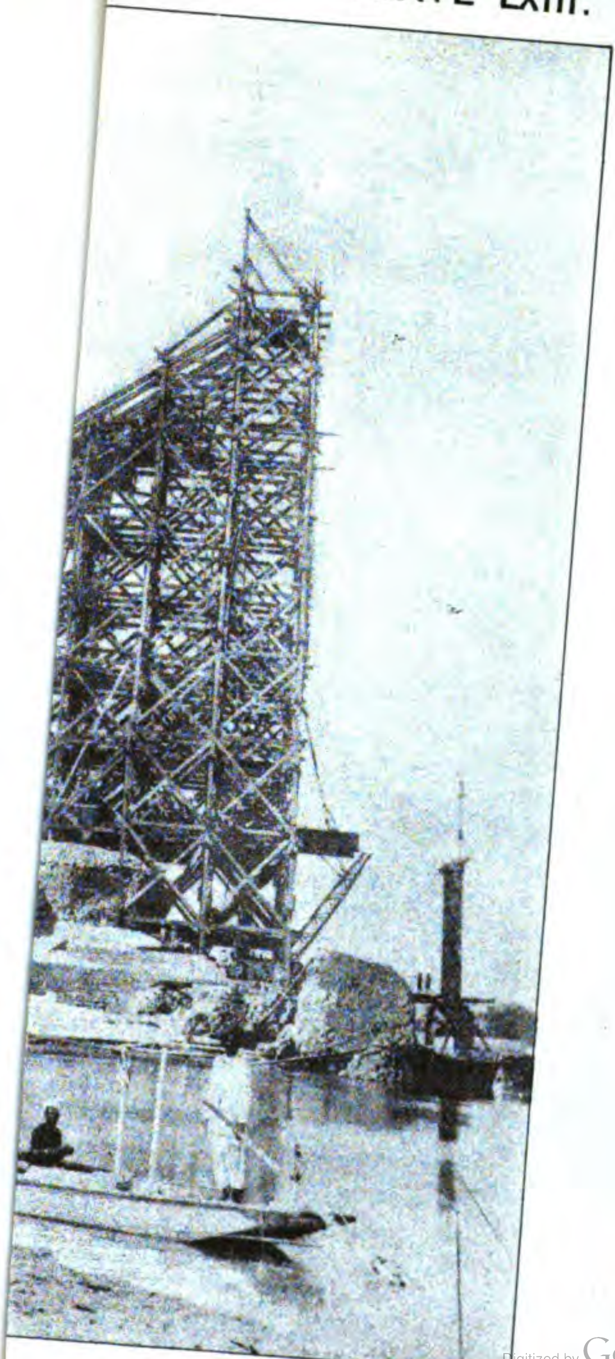

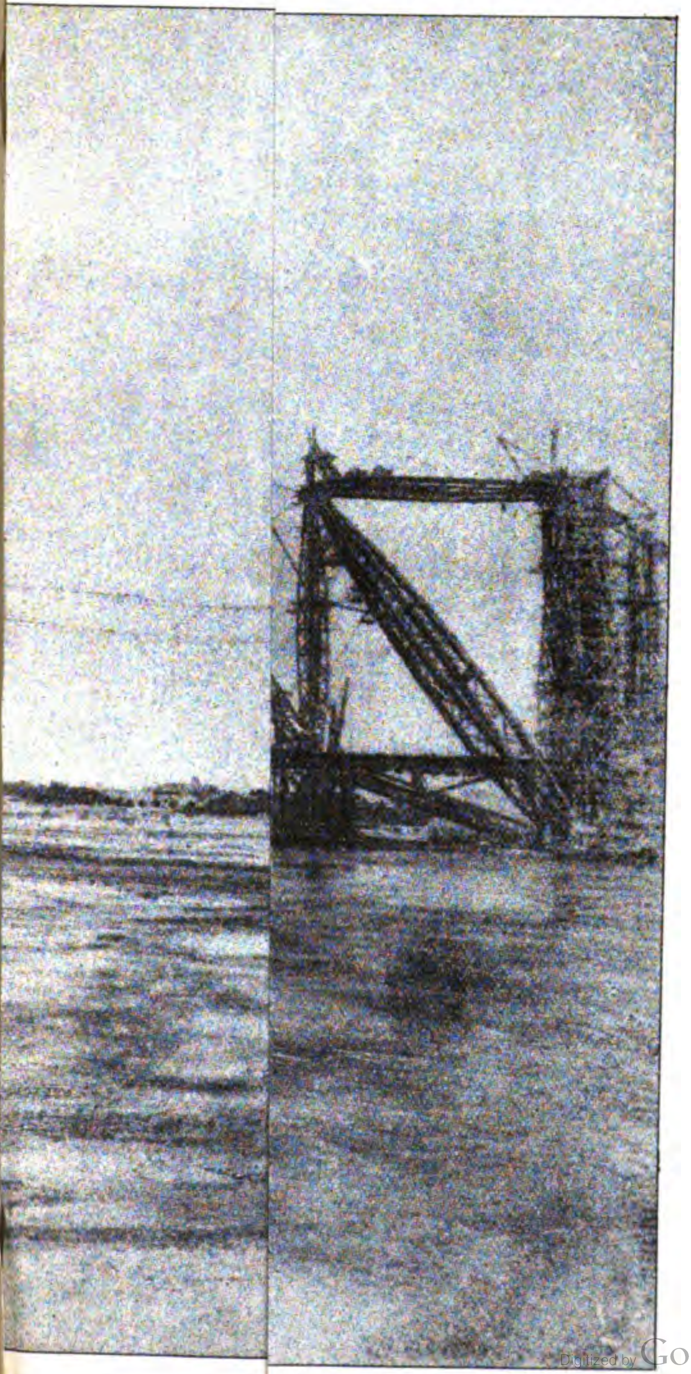

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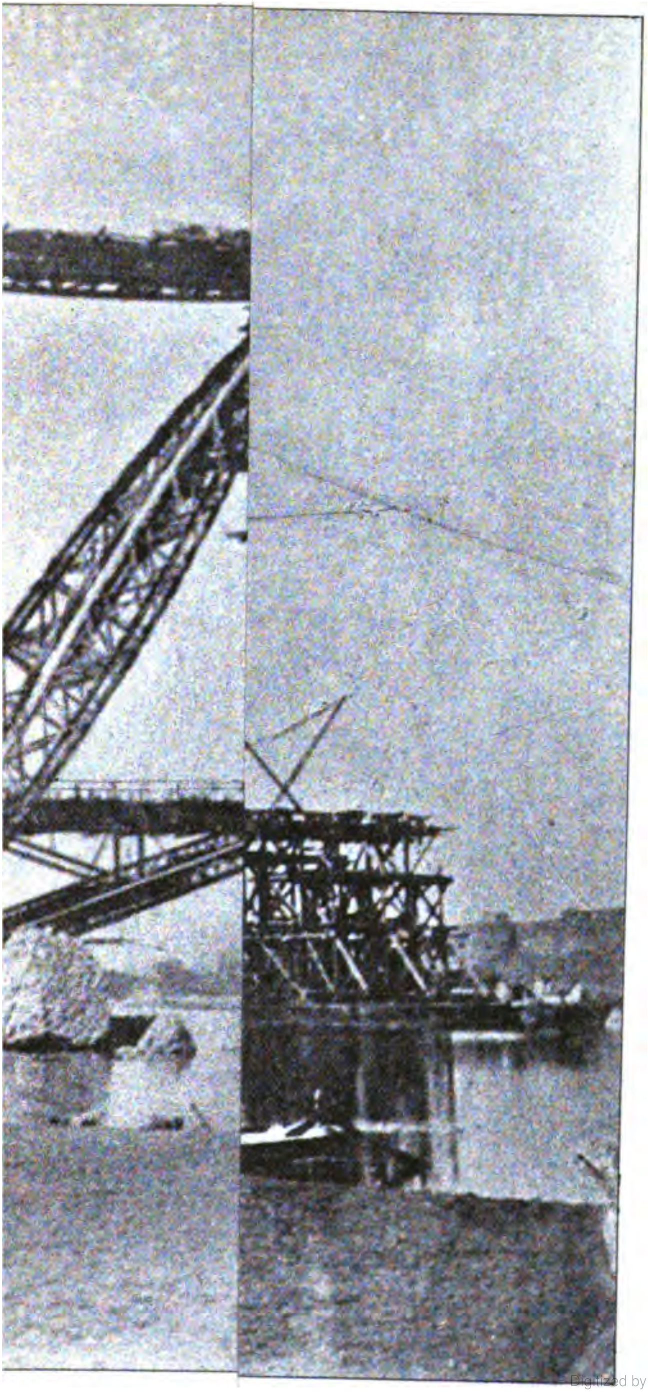

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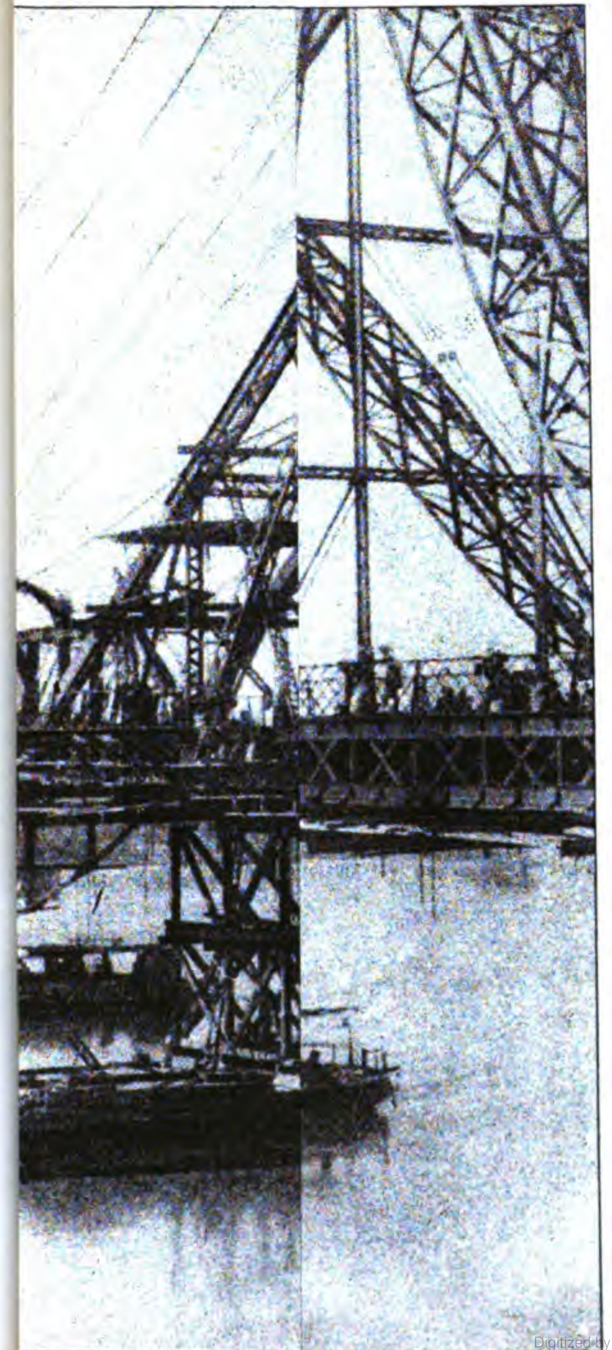

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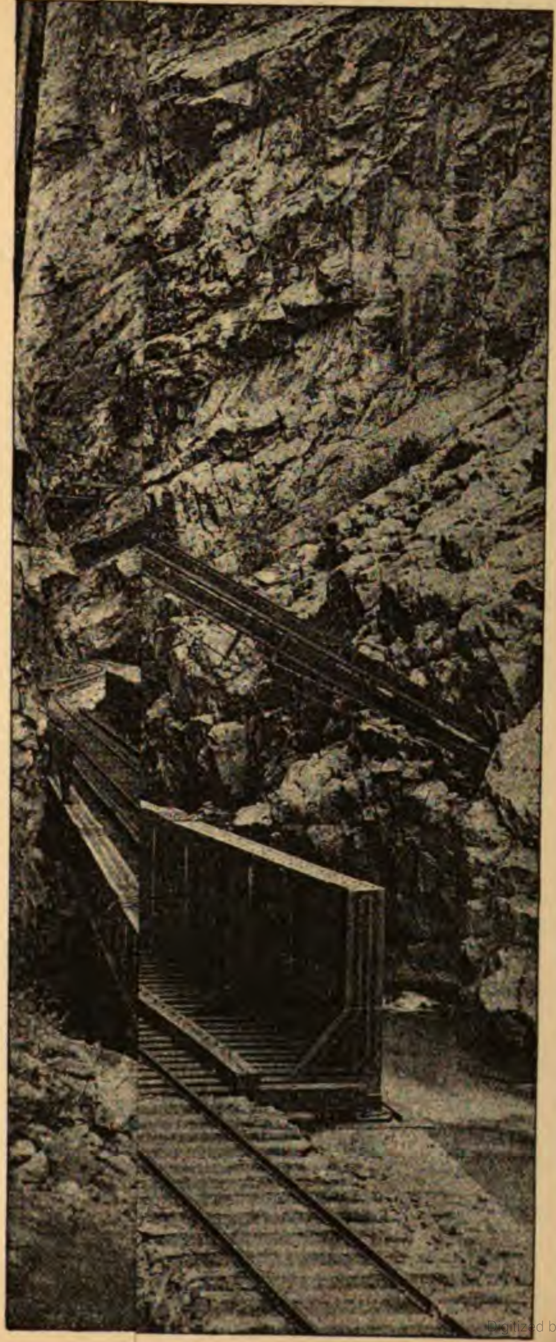

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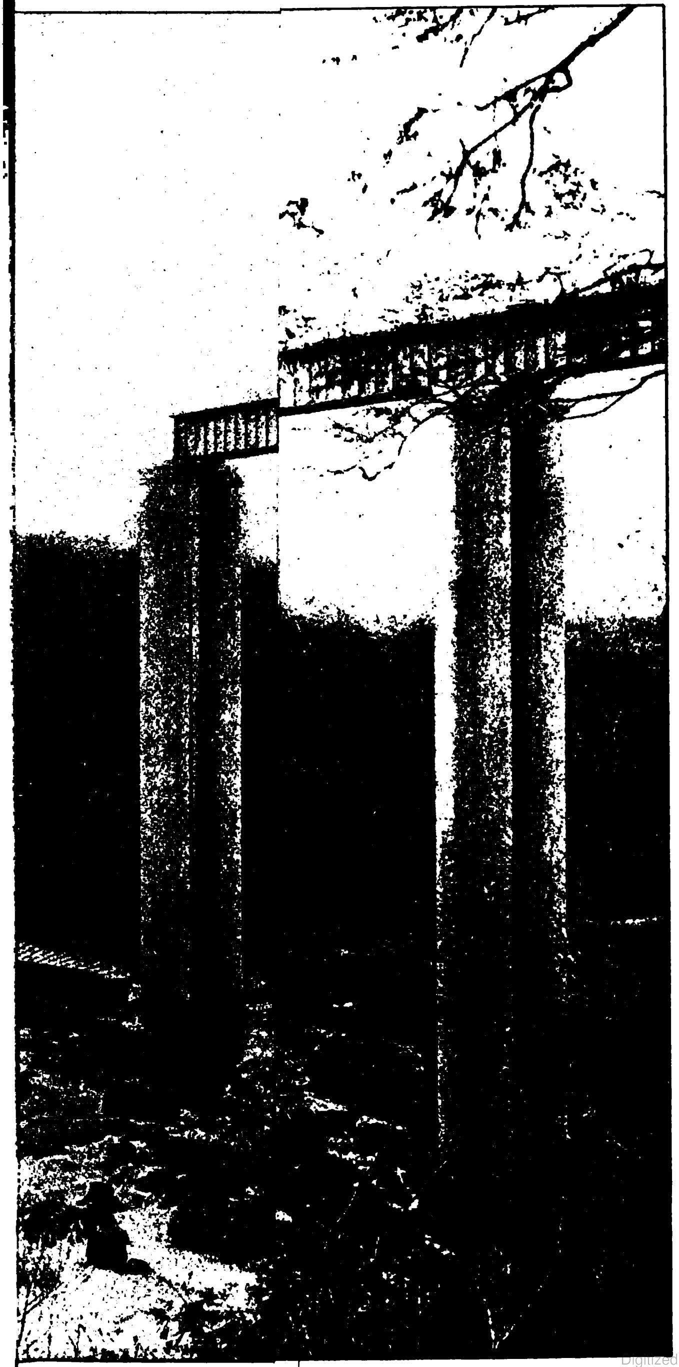

RAILWAY C

PLATE LXX.

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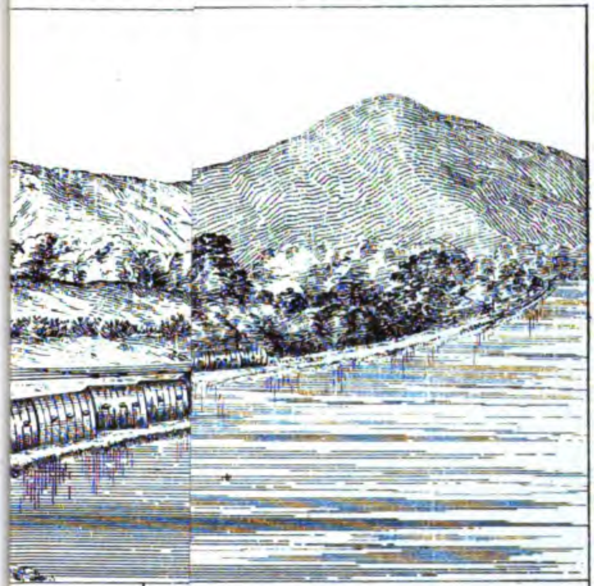
PLATE LXXII



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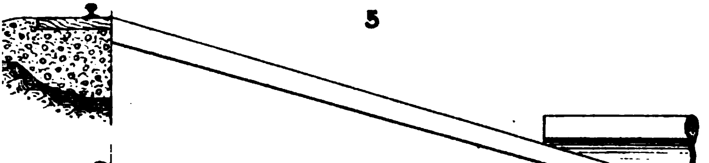

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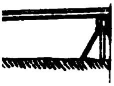

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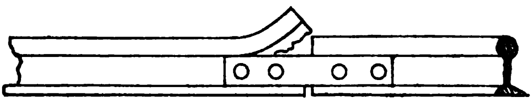

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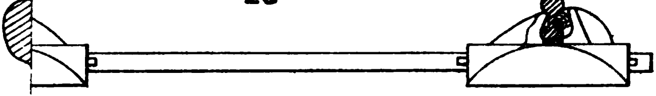

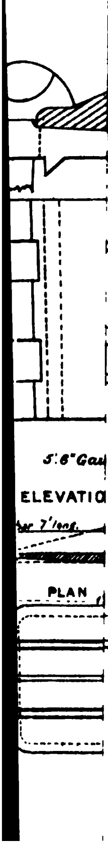

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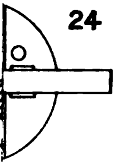

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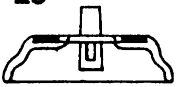

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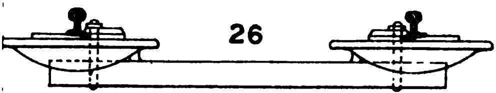

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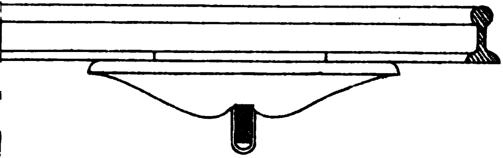

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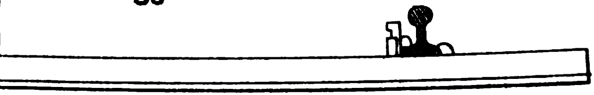

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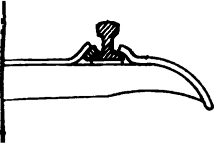

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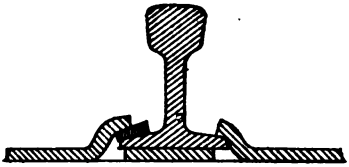

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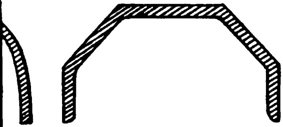

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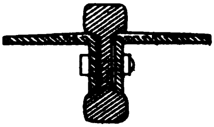

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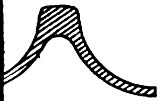

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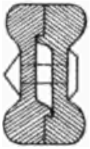

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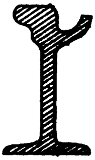

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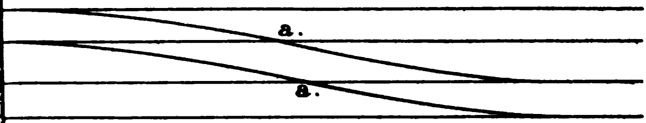

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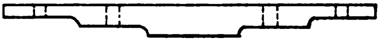

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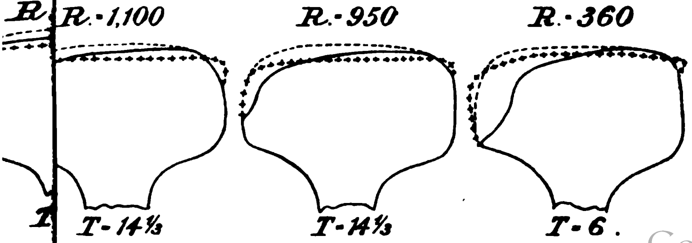

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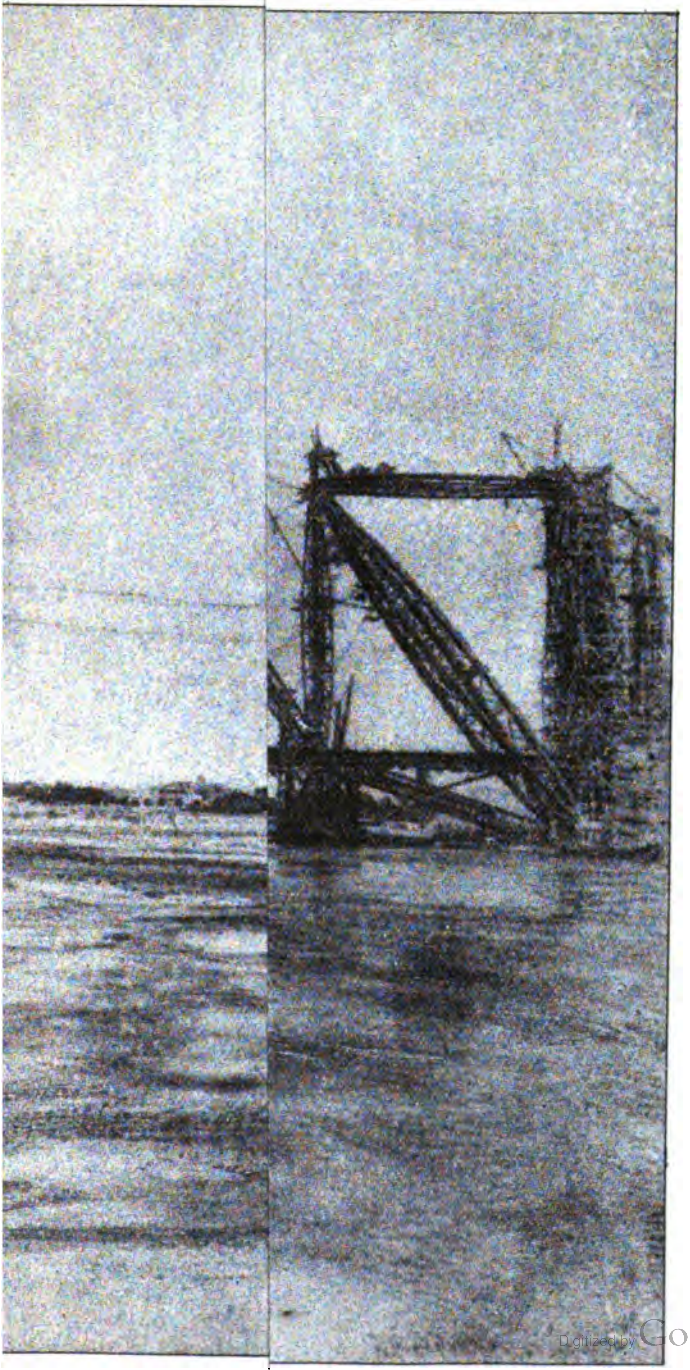

PAPER IX.

THE ORGANIZATION OF THE MILITARY AND ADMINISTRATIVE SERVICES DURING A SIEGE.*

By Major C. B. Mayne, R.E.

(*Lecture given at the School of Military Engineering*, 31*st October*, 1895).

The subject is here dealt with in reference to the defence of a land fortress, when besieged, in a friendly country. All our textbooks deal very fully with the military and technical aspects of the defence of fortified places, but very little is said indeed about *the administrative arrangements required to enable the military defence to be maintained in the most efficient manner possible.*

It is almost impossible to find anything written on this subject in the English language, and consequently the following remarks must be taken merely as suggestions as to what can be done and should be done in a place likely to be besieged. It is not to be assumed that all the measures recommended to be taken in the following pages have ever been carried out in any single siege of the past, but some have been carried out in one siege and others in other sieges. These various measures have here been collated and brought together so as to form a consistent system suited to our own military organization, and it is believed that this is the first time that such an attempt has been made in English military literature.*

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* The principles advocated in this paper are applicable, with suitable modifications as to details, to the smallest as well as the largest of fortified places. The case of a large fortress is alone considered in the following pages, but the reader can make the necessary suitable modifications for different cases.

Now the first thing to be remembered in all military matters is that the armed and organized body of men called "the army" is not a self-contained perpetual-motion machine; it is an organism having *daily* needs that require to be *daily* supplied, in order to prevent its annihilation by exhaustion. Doubtless the object of an armed force is to fight, but it is the duty of its commander to bring it to the fight in the best possible condition for fighting, and as the number of days spent in fighting are few, while the necessity for supplying the needs of an army (which is a consuming organism) is constant, a leader in the field is compelled to spend far more time considering over his administrative arrangements and their results than he has to spend over his arrangements for battle only.

But at the same time it must be acknowledged that it is always necessary to make the military and technical requirements of any particular phase of war our first study, because it is very essential to study all matters in their most critical aspect—the battle—in order to learn fully, not only all the requirements that have to be met, but also the mutual relations of the various arms.

It almost goes without saying that such a large subject as is now being considered cannot be dealt with in a complete and adequate manner in a short paper, and, therefore, all that can be done under the circumstances is to present to the reader a bare outline of the many considerations that are involved in the expression "the defence of a land fortress." It is not intended to deal with the somewhat delicate questions of naval aid and assistance to the land forces, and of the mutual relations of the sea and land armaments and forces acting together at our naval bases. These points, however, are very important ones to be thought out, especially in the British service, in order to obtain the maximum effect from the combined efforts of the sister services with the minimum of friction. But so far as the object of this paper is concerned, nothing will be said about them.

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* The writer has to acknowledge his obligation to a brief French pamphlet giving an analysis of a German work by Major-General von Kamptz, entitled *The Organization of the Auxiliary Services of a Besieged Place*, 1877. As the writer is unable to read German, he has not been able to avail himself of the contents of this larger work, but as General von Kamptz's recommendations apply to a different military and civil organization to our own, his remarks can only be of general interest to English officers. The French Government publish regulations relating to besieged places, but they only touch on a very few of the details that have to be considered. However, the French official *Décret portant règlement sur le service dans les places de guerre et les villes ouvertes* is worth being carefully studied. The above are the only two works bearing directly on the subject that the writer has met with.

As it is very important that the expressions we use should be understood, the meaning of two words, as used in this paper, must be defined before going further, viz., *fort* and *fortress*.

By a *fort* is meant a small fortified locality whose influence does not extend further than the efficacious range of its armament.

By a *fortress* is meant a large fortified locality whose influence extends considerably further than the efficacious range of its armament. This long range of influence depends partly on the offensive power of its garrison, and partly on the strategic *rôle* that the fortress is expected to play during a war.

Whatever may be the existing differences of opinion among military engineers as to the designs of the details of a land fortress, there is a complete agreement as to the general form that such a fortress will assume, viz., a central locality (that has to be protected from capture by an enemy) surrounded by a number of detached forts placed at a considerable distance from the central locality, and at certain intervals from one another, the forts and intervals being guarded by troops and guns. This general principle, when applied to a concrete case, gives rise to many questions, such as, shall the central locality itself be fortified or not? and if to be fortified, how—by permanent, semi-permanent, or field works? At what intervals apart from each other are the detached forts to be placed in the girdle they form round the central locality? and at what distance are they to be from this latter? What should be the design of the detached forts—are they to form emplacements for artillery only, or for infantry only, or for both? Are they to be of a field work, semi-permanent, or permanent type of construction? And so on. But such questions cannot be answered *per se;* they depend on many controlling factors, such as the importance of the *rôle* that the fortress will have to play in war, the quality and quantity of the troops which are to form its garrison, the difficulties that the attack and defence have to deal with, the possible duration of the war, the power and technical use of the armaments of the opposing forces, etc. Every case has to be dealt with on its own merits. But there is a general agreement on the following points:—

1. If the central locality is to be fortified, all that is required for the purpose is a strong obstacle earthwork of simple trace.

2. The outlying detached forts should have as one of their chief duties the prevention of the enemy forming a permanent lodgement within the area they encircle until two or more of them have been captured.

3. The intervals between the outlying detached forts are to be strengthened by such field works as will enable the defending infantry and artillery to most efficaciously carry out their respective duties.

4. The central locality and the outlying forts should all be connected by telegraphic, telephonic, railway, and road communications, so as to speedily effect the conveyance of orders, information, guns, ammunition, stores, etc., to wherever they may be required.

5. One or more interior field positions must be prepared during the siege behind that portion of the line of detached forts that is being specially attacked by the enemy.

6. In these days of accurate artillery fire of great power, the invisibility and mobility of the artillery armament, and the invisibility of all works, are very necessary to minimize the possible efficacy of the enemy's fire and to reduce the expense of construction.* Visible armoured defences are advocated by some military engineers.

7. An ample provision of intermediate and expense magazines near the fighting line is very necessary.

8. Means of observing the enemy and the effects of our own fire from a height (*i.e.*, by balloons, field observatories, towers, etc.) are very desirable.

9. The quality and numbers of the troops forming the garrison must not be below a certain minimum, nor above a certain maximum, if a good and prolonged defence is required, and if the field armies are not to be unduly weakened.

10. An active defence is essential; this depends on a bold, determined and vigorous commander.

Thus, in making arrangements for preventing the capture of a place by fortifying it, we have to decide on which of the many considerations that bear on the question we consider to be of the greatest importance for the particular place, time, and conditions of the war. Given a certain sum of money, how is it to be spent? On men, works, armaments, communications, magazines, supplies, etc.? For what is spent on one means so much less for the others. But whatever is done, we must bear in mind that the line of detached forts marks that fighting position which the defenders must hold on to as long as possible in order to preserve for the defence the greatest advantages possible. Once this line is penetrated, the conditions of the attack and defence become more equalized. And we must also remember this fact, that unless the attackers are only trying to starve the defenders into submission, the artillery of the defence must sooner or later be overpowered, unless assistance arrives from the outside. Hence the ultimate defence must rest on the infantry of the garrison, aided by such artillery as has not been silenced. In fact, throughout the whole defence the infantry must form the backbone of it, and the function of the artillery and engineer services is to give assistance, either directly or indirectly, to the infantry in its arduous duties. In war, the artillery arm is essentially the leveller of obstacles—material and moral; it levels the way for the subsequent infantry efforts. The engineer arm is essentially the handmaiden arm, and to fulfil its duties as such it must understand the requirements of all the other arms and administrative services.

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* It must be remembered that the money available for defences is limited.

So far we have considered the subject of fortresses without having referred to the object for which they have been constructed. This object, however, is a vital point to bear in mind, *as we cannot properly carry out the defence of any fortified place without first distinctly bearing in mind why we have fortified it.* Thus, before considering details, we must first fully realize the principles underlying the defence of a fortress, or rather the purpose for which the defence is undertaken. This is a necessary preliminary, because *details are only conditional things;* they are only the concrete application of abstract principles according to the end in view and the available means at hand.

The object of war is the annihilation of the enemy's means of resistance, *i.e.*, of both his troops and the supplies they require for their existence as troops. This object we strive to obtain, partly by depriving the enemy of his sources of supply by means of capturing his territory and collections of supplies, but chiefly by endeavouring to bring, at the right times and places, superior forces of our own upon inferior forces of the enemy, and so to defeat the latter before they can receive assistance. Fortification, if properly used, is only one of the means at our disposal to attain this end, for its whole object is, or should be, to assist in obtaining a local superiority over the enemy by the aid of artificial means.* We do this by selecting such places to be fortified as the enemy will desire to capture, either for his own interests or to weaken our own means of resistance, and then (1) so altering the surface of the ground around it as to enable an inferior force to resist one greatly superior to it until extraneous help comes to relieve it; and (2) so garrisoning it as to compel the enemy to detach a much larger force than the garrison to prevent the latter attacking his field armies in flank or in rear.

Thus all fortification must, for its best use, be viewed from both a strategical and a tactical aspect. If it be but technically regarded, apart from its tactical and strategical aspect, and be looked on as an end in itself, it will be misused, and may have a disastrous instead of a beneficial effect upon the result of the war. An army in the field must be able to move and be able to procure *with certainty* the supplies of all kinds needful for its existence as an army. That is to say, each army must secure for itself the free use of roads, railways, and waterways, etc., and also its rear from attack, and it must further capture and hold securely all the centres of production and storage in its vicinity. While trying to procure these objects for itself, each army tries to deprive the enemy of them whenever this can be safely done. Consequently all lines of communication (especially railways and such defiles as bridges and mountain passes), all centres of production or manufacture, all magazines and depôts, especially of warlike stores, and all important naval dockyards, will form objectives for the enemy's efforts when the opposing army is not in his immediate presence. Hence the more important places of production and storage, which are also always on the great lines of communication, and which will certainly form objectives for the enemy's efforts to capture them, are usually chosen as places to be fortified, and these should then be adequately garrisoned and armed, and otherwise provided with the necessary means for being defended. And here, in passing, it is well to remind ourselves of the fact that *fortifications without armament and supplies of all kinds and an adequate and determined garrison are useless.* They are then only like a lifeless body. In fact, fortifications should be constructed to assist the garrison of the place, that is, the latter should be first considered and then the former. *Fortification is only of*

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* "There are some military men who ask, of what use are fortified places, entrenched camps, and the art of the engineer? We ask them, in reply, how is it possible to manœuvre with inferior or equal forces without the assistance of positions, fortifications and all the supplementary means of the art?"—*Conversations of Napoleon*, by Montholon.

value according to the value of its garrison, armament, commander, and the means provided for making a prolonged defence. It is only the last of these conditions that we are going to deal with in the following pages.

The places to be fortified being thus centres of production and storage, they are places having a large civil population. This is an important fact to bear in mind, and the places selected for being fortified must, therefore, be made secure from the chance of a serious distant bombardment, which may seriously disaffect the populace, and through them the troops, besides destroying the very means of production and storage we are so desirous to protect. Hence the necessity for placing the outer line of detached forts and other outlying defensive works at a distance from the central locality (*i.e.*, the centre of production and storage). This distance is chiefly governed by the ranging powers of modern siege artillery and by the features of the ground in the vicinity of the place. The situation of the central locality is usually in a valley or hollow, astride of a river or railway, or at a junction of roads or other lines of communication, and the outlying detached forts and works are placed on the surrounding heights. Consequently, the line of detached forts, *i.e.*, the line of battle, has to be chosen within narrow limits of ground, and within these limits the best battlefield possible, under the circumstances, has to be selected, even though it may be one that would never have been taken up by a field army free to choose its own fighting positions on the threatre of war. This explains, in many cases, the difficulties which the defenders of a fortified place have had to contend with, for they have had to defend ground ill-adapted for the best defence.

Tactically speaking, the art of fortification consists either in improving the natural tactical advantages, or of minimizing the natural tactical disadvantages, of the ground to be contested for, by means of artificial works. Hence the true object of fortification is, by artificial constructions, to enable a smaller force to hold a much larger body in check for a considerable period, and thus to have a powerful strategical influence on the campaign. But while fortification in its adaptation to given localities is a branch of tactics, the choice of the particular localities that are to be fortified, and number and quality of their garrisons, lies within the province of strategy, and in this respect fortification is a branch of strategy. But, in most cases, a fortress should not only have a strategic defensive capacity or negative *rôle;* it should also have a strategic offensive capacity or positive *rôle*, and this can only be secured by its being given a mobile field force over and above its bare defensive garrison, that can sally forth and strike a serious blow on the enemy's flanks and rear.* Fortresses which are not given this mobile field force will not play such a *rôle* in war as may be expected from them in order to compensate for their great cost, viz., to draw a still greater portion of the enemy's forces away from the field operations than those which form the garrison of the place. This mobile field force should not be too large, and should be composed of troops fit for manœuvring.

Provided that the other troops of the garrison are backed up by such a mobile field force, they need not be up to the standard of the troops composing the latter, for from the great increase of artificial strength that fortifications give to troops behind them, the defenders can be largely composed of such relatively inferior troops as are unfitted for field warfare. Consequently, fortification enables a greater proportion of the best troops of a nation being used for the field warfare than when such fortifications do not exist. The places fortified are those which have to be held and defended whether fortified or not, and they are only fortified to reduce the number and quality of the troops required for their defence.

Of course, all the places to be fortified in any country should be so selected as to form a connected system in agreement with the general plan of national defence, and in this system and plan each fortress should have its definite *rôle* allotted to it. If the fortress does not fulfil its *rôle*, then all that has been expended on it has been uselessly spent, and it is the duty of every Government to ensure that all its fortresses shall be efficiently well equipped in troops, material, and stores, and be given capable commanders, in order that they may individually be able to play the part assigned to them in any possible war. This part, of course, must be one that will hinder the enemy's movements and weaken his field armies, and this can only be effected by the action of the troops that the various fortresses are garrisoned with. These troops require also an adequate provision of warlike stores, food, and other supplies, or else they cannot act so energetically as to ensure the *rôle* of the various fortresses being carried out. If this *rôle* fails in execution, then the success of the national defence is endangered. Hence we see the national importance of ensuring the efficient defence of the fortresses of a country, and that this defence should be of as long duration as possible. A capitulated fortress is a double disadvantage, for it is a loss to the nation to which it belongs, as neither it nor its garrison can any longer play any part in the national defence, while it is a gain to the enemy, as it frees a number of his troops for use elsewhere, and allows a large quantity of valuable stores to fall into his hands. We have further to remember that a besieged place is certain to fall into the hands of the besiegers, if it is not succoured and re-supplied within a certain time. But enough has been said to show that, in every case, it is the absolute duty of the defenders to prolong the resistance to the utmost limit possible, in order (1) either to facilitate the work of the field armies by keeping tied to the fortress the greatest number possible of the enemy; or (2) if they succumb, to at least make the enemy pay as dearly as possible for his success. And it is also the absolute duty of the defenders to act in such a way as to cause the strategical offensive influence of the fortress to be felt, or else it will not be fulfilling its proper *rôle* in the war. This can only be done by an active defence, which has the further advantage of keeping up the *moral* of the garrison. We may thus summarize *the conditions under which the defence of a land fortress is undertaken. In such a fortress we have a stationary garrison proper of relatively inferior troops, a proportionate mobile field force of all arms, if possible of relatively good troops, and a large civilian population to deal with. And the defence must be so conducted as to produce a marked strategical effect on the course of the operations by compelling the enemy to attack or watch the fortress with a much greater number of troops than are in the fortress defending it.*

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* Cases may occur in which a place may be fortified in order to prevent the enemy possessing himself of it. In such a case, the fortress would only play a negative *rôle*. As an example of such a place we may take the case of a naval dockyard of a maritime power far distant from the probable scene of decisive land operations.

Having a civilian population, what are we to do with it? The people cannot supply themselves for a siege of long duration, and so will eventually have to be fed.* Shall this be done without a return from them in the shape of labour? An idle population is always a source of danger and disaffection. They must, as far as possible, be kept employed at their own trades, or in providing for the wants of the troops, for which they should be given pay, either in money or kind, or both.

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* At Metz, 1870, and at other places, efforts were made to compel the inhabitants to lay in provisions and fuel for several months. But in spite of this, the civilian population had to be rationed in time.

One of the secrets of a successful active defence lies in relieving the troops of all duties that can be performed by civilians without these latter incurring certain danger, and in assuring to the troops the supply of all the necessaries they require for fighting and living. The troops are then made freer to undertake offensive operations against the enemy, especially before the investment is completed.

Many of the civilian male population can be enlisted for service during the siege and trained sufficiently to fill up the gaps that occur in the ranks of the regular troops through death, wounds, and sickness.

The duration of the defence depends on the strength and quality and spirit of the garrison, and of its commander, on the perfection and state of readiness of the fortifications and armament, on the amount of the supplies, warlike and otherwise, contained in the place, and on the facilities that the place itself affords for replenishing the expended guns, ammunition, etc. Consequently, the defence of a fortified place really begins in peace time, because it is in peace time that the mass of the fortifications must be completed; guns, ammunition, food and stores collected, and local manufactories and storehouses for these established. Care must be taken to provide *everything* that is required, and in adequate quantities. A deficiency in any one essential article may cause the fall of the fortress even though there may be an abundance of other things remaining. The guns need not all be mounted in position in peace time, nor all the ammunition distributed among the various intermediate and expense magazines, but they should be within the place on the outbreak of hostilities. Also important places should have facilities provided for the manufacture of explosives and ammunition, because it is not always possible to foresee the expenditure of such stores.

Just previous to hostilities, the fortified places would become the receptacles of an immense amount of stores of all kinds, especially if they are in the vicinity of the expected scene of actual fighting, as they would then have to act as bases of supply to the field armies. But such a quantity of these stores must be rigidly set apart for the use of the total garrison and civil population of the place as will be sufficient to last them for some months.* A large margin must be allowed for destruction by the enemy's shells, for deterioration, thefts, fires, the support of prisoners of war, and for any extra troops and civilians* that may possibly become shut up in the fortress. But it is the duty of the commander-in-chief of the field forces to prevent, if possible, such a contingency as the last happening. When once a fortress has its full complement of troops, all extra troops placed in it are a double source of weakness, as they eat up food without adding materially to the strength of the place, and their absence from the field armies weakens the latter.

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* The French regulations forbid the field armies drawing in any way on any of the supplies set apart for the use of the fortress, or on the "requisition zone" allotted to the fortress.

Every fortified place is placed under the command of an officer, called the GOVERNOR, who is nominated by the Government for the purpose. And on account of the numerous duties and responsibilities that fall on him, it is very necessary that he should organize all the various elements, military and civil, under his command, so as to make them all aid in the task of defending the place. He should be accorded full legal powers for this purpose.

Although the exact methods of the defence will depend on the methods and nature of the attack—whether this latter be an attempt at surprise, a sudden assault, a blockade, an investment with or without a bombardment, or a regular siege—yet the Governor has to be prepared beforehand for either, or all, of these, and he must accordingly make such general preparations as will enable him to meet all contingencies.

Before considering the actual organization of all this work, we must first consider more in detail everything that is required to be done for carrying out the defence of a besieged fortress, for it is only when we have done this that we can decide on the organization of the means at the Governor's disposal to meet it.

A siege is nothing more than a battle of many days' duration,† and during which time each side makes every effort to take every advantage possible that can be derived from the ground naturally, or by industry applied to altering its form. While this prolonged battle is in progress the troops have to be supplied with all they want, besides being fed, sheltered, and given rest. We will now consider, as briefly as is possible, the different kinds of work that have to be carried out for this object.

1. *Infantry and Cavalry Work.*—These troops have to carry out

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* At Metz, 1870, 15,000 labourers were collected and employed at throwing up new works. These men and Bazaine's army of 160,000 men, besides horses, were enclosed in the fortress by the Germans, and as no provision had been made for them they only hastened the fall of the place by starvation.

† It is often said that a battle is only a siege epitomized. This is an entirely wrong aspect of the matter, and the writer regrets that he himself has made use of the expression in his work on *Infantry Fire Tactics*.

the outpost, guard, and fatigue services, reconnaissances and foraging expeditions, and furnish working parties for all works that have to be constructed in the immediate presence of the enemy.

2. *Engineer Work.*—The engineers have to arrange for the completion and strengthening of all existing incomplete or weak works; the laying out and construction of new works (batteries, magazines, traverses, casemates, bombproof cover and shelters, redoubts, field works, field observatories, etc.); the clearing of the field of fire of all houses, trees, or anything that will assist the enemy; the preparation of villages and farms in the line of defence to resist attack; the clearing of ditches; the construction of obstacles; the preparation for destruction of the bridges, etc., on the enemy's line of advance; the preparation and carrying out of inundations on ground likely to be of use to the enemy; the excavations of mines; the maintenance of the existing internal communications (rail or road), and the construction of new ones, including bridging work; the laying and working of electric message communications and electric search lights; the construction of barrack and hospital accommodation; the provision of drinking water for men and animals, and of water for a number of other purposes; the erection of workshops and storehouses (expense, intermediate, and main) for the various administrative departments; the maintenance, construction and supervision of sanitary works; the defence of any existing waterways by barriers and torpedoes; the perfecting of the movement of water in the ditches of works when necessary; the calculation, collection and storage of tools, materials, and means for effecting repairs and constructing works; the calculation, collection and organization of the necessary labour, etc., etc.

3. *Artillery Work.*—The artillery will have to carry out the arming of the forts and batteries; the mounting of the various kinds of ordnance; the filling of the magazines (expense, intermediate, and main); the preparation and issue of ammunition; the preparations for observing the effects of the artillery fire; the measurement of ranges, etc., etc.

4. *Transport of Supplies to the Front.*—All the above heavy work, dealing with materials that are liable to be damaged (guns, revetments, etc.) or are being constantly consumed (ammunition, etc.), and which must be repaired or replaced, will require a corresponding large amount of *transport.* Besides this, food, water, fuel, and other supplies will have to be continuously brought to the front, and sick and wounded carried to the rear. Hence many men are required

for this transport work and for the loading and unloading it entails.

Further, as the Government transport will not be in any way sufficient for the above work, all the vehicles and draught animals in the place and its vicinity must be enrolled, collected, organized into units, and told off to the respective duties that they will have to perform in carrying out the transport service from the parks and depôts in rear to the front and the carriage of wounded to the rear. This entails the grouping of the requisitioned transport at certain selected points or *Transport Stations*, which must be capable of being furnished with drinking water, and have quarters for the drivers, and stables or sheds and forage stores near at hand to ensure a regular stable service being carried out. In connection with this kind of transport service it will be necessary to provide workshops for the manufacture and repair of saddlery, vehicles, etc., and forges for shoeing the animals.

Any existing rail or water communication from the rear to the front would also be made use of for this transport service, but the work would fall on engineer officers, and will be referred to again presently under a separate heading.

5. *Transport of Wounded to the Rear.*—It is very necessary to establish a large number of stretcher-bearer companies and ambulances to prevent the fighting troops having to carry their own wounded to the rear. The companies and ambulances would be quartered near the "first dressing stations" in the defensive line. As a siege is a prolonged battle, the work of these companies and ambulances will be very constant.

6. *The Communication Service.*—The service of the rail, tram, and water transport communications within the area of the fortress is a very important matter, as it will enormously reduce the number of workmen, vehicles, and transport animals required for a purely road communication. Wherever possible, radial railways and tramways should connect the various central artillery and engineer parks, main magazines, and supply depôts with the outermost line of the defence—this in addition to a circular railway connecting the outlying detached forts with one another. This work should be mainly done in peace time, and, where possible, the lines should be so located as to make it difficult for the enemy to hit them. Otherwise we can only have a night service on those parts of the lines near the fighting position. Sometimes these lines can be used for firing guns mounted on suitable wagons; then these guns can be

moved from point to point as required. If there is any chance of the steam and smoke of the engines betraying their position and movement to the enemy, then horses can be used as the motive power. If possible, the railway stations and yards should be inside the town that is to be protected, so as to avoid having to construct special defences for them, for anything requiring such special defences is a disadvantage, as it increases the number of detached works, and necessitates a more numerous garrison. Every terminal station possesses much material—rails, locomotives, carriages, cars, tools, etc.—which must be protected from seizure by the enemy, and kept for the use of the defence. In maritime places the sea front would receive assistance from the Navy, which, if supreme at sea, would keep the place supplied during the siege with all it required. But as the fleet will usually be absent, a service of water surveillance should be established by organizing a small flotilla of guard boats. To permanently block the channel of approach or entry to a sea-port is not always wise, and here torpedoes (fixed or mobile) and booms, or floating barriers well under gun-fire, come into play for this purpose. Where a river or canal passes through the fortress, it must be bridged at several points, and the waterway be closely watched, both up and down stream, to prevent the enemy getting access to the place by it. Here again it is often wiser to guard the stream by means of gunboats, barriers, and torpedoes placed under gun-fire of land batteries than by permanently blocking the channel by means of sunken vessels or other obstructions. The above works would be placed under the charge of engineer officers, except when naval officers are available, who would be utilized, when available, to carry out the water surveillance in order to reduce the heavy work that falls on the engineers of the defence.

7. *The Transmission of Messages and Orders.*—The service of the message communications, whether by telegraph, telephone, signals, or messengers, is one of very great importance. The telegraph and telephone are means eminently suited to place the Governor, on whom the defence of the whole fortress rests, in rapid communication, not only with the heads of his administrative departments and local commanders, but also with each of the detached forts and groups of batteries. For this purpose it is very necessary that subterranean wires should be laid to prevent their being injured by the enemy's projectiles. There should be an ample supply of instruments in store, so that a damaged instrument can be rapidly changed and repaired afterwards at leisure. Although many trained civilians

are now to be found in every large town capable of putting up and repairing telegraphic and telephonic lines and instruments, yet there is a great difficulty in procuring trained telegraph operators, who require years of work to attain to any efficiency. A wrongly sent message may be more disastrous than no message at all. Consequently, it may be of use to have in store a number of instruments of such a kind as can be fairly accurately used by partially trained operators. Flag signallers can be easily trained in a short time. Signalled messages can also be sent by throwing an electric light on distant objects, or by lamps.

8. *Powder Magazines and Laboratories.*—The service of the powder magazines and laboratories always forms a heavy tax on the labour power of the artillery, because such work must be carried out by trained artillerymen, who understand the management and methods of storage and issue of ammunition and explosives.

9. *The Artillery Park.*—The service of the artillery park in a besieged place is a work that demands great activity and self-denial. The duties are manifold, being both administrative and executive. They comprise the charge of books, accounts, store ledgers; the care and issue of guns, carriages, ammunition, powder, explosives, shells, etc. This park should also possess workshops for the repair of damaged gun carriages and other articles used by the artillery.

10. *Gun and Shell Foundry.*—It is very important to establish in every defended fortress a gun and shell foundry, and also

11. *Powder Factory.*—A manufactory for powder and other explosives.

These last two kinds of work have frequently been established during celebrated sieges in order to enable the defence to be prolonged. The supply of guns and ammunition ordered for the garrison may have been under-estimated, or not have been collected in time, or much of it may have been destroyed by the enemy's fire. Consequently these manufactories should always be established as soon as possible, however small the turn-out may be. Many cases occur in history of the decisive influence on the course of a war of even prolonging the defence for a single day.

12. *The Engineer Park.*—The service of the engineer park is also one of the greatest labour and self-denial. On the engineers fall all the works of the defence and of the communications, and consequently the multitudinous kinds of work that have already been enumerated. All the materials (especially sandbags, rails, and wood and brushwood of all kinds) necessary for the execution of these works should

be collected, prepared, and stored, with the greatest care, before the arrival of the enemy, so as to be able to carry out the works without loss of time at the moment of need. Also, the number of workmen required has to be estimated and arranged for, and the time in which each kind of work can be done should be calculated. All these works require careful organization and allotment to distinct officers, who must be responsible for their execution. In addition to all the executive work, there is the keeping of books, accounts, store ledgers, etc. To the engineer park there must be attached various workshops, for sawing timber, carpentry, ironwork, etc., etc. These shops require fitting up.

13. *The Water Supply.*—The supply of water in adequate quantities is a very serious consideration in every defended place, and this work devolves on the engineer officers, who must make ample preparations for its safe collection, storage and distribution, and look to the means for preventing its being wasted. The supply required must be sufficient in case of need for the cooking, drinking and washing requirements of all the troops and civil population, for all the transport and slaughter animals, and for the requirements of all the various workshops, steam engines, and sanitary work of the place. In some cases the supply of water for drinking and cooking purposes will have to be separate from that required for all other purposes. If necessary, storage tanks and cisterns of adequate capacity must be prepared and placed in safe situations.

The provision of water, so necessary to support life, must be assured in a besieged place under all circumstances. If the supply is at all limited the utmost economy must be exercised, and a rigid control placed on its consumption. For this purpose the work at breweries, distilleries, etc., or other places using water to manufacture things not absolutely necessary to life, would be stopped.

The sources of water supply from the rivers or wells supplying the whole fortress to the supply cisterns in a fort should be protected from capture by the enemy, and from all possible sources of pollution.* If there is any danger of the enemy cutting off the existing water supply, new means, secure from his efforts, must be devised for getting water.

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* In 1870, at Metz, the Germans captured the main source of the supply of drinking water of the town, and in consequence of this the impure river water had to be used, which produced much sickness. At Phalzburg the Germans, when digging their trenches, came across the main water supply pipe, which they cut, causing much inconvenience to the defence.

14. *The Commissariat* Depôt.*—A large commissariat depôt will have to be formed to hold very great quantities of food and forage of all kinds, fuel and lighting. Attached to this depôt there will have to be corn mills, bakeries, cattle yards, slaughter houses, butcher shops, etc., for corn will have to be ground, bread baked, meat animals fed and watered previously to being slaughtered and cut up for distribution.

It is an open question whether the commissariat depôt should not also undertake the cooking of all the food issued, in which case cook-houses would have to be organized. Food and fuel have to be taken out to the troops, and it may be as well to take the former to them cooked (while being kept warm in suitable vessels), so as not only to save transport and waste of fuel, but also to lighten the labours of the troops, and to reduce the number of men taken from the ranks for cooking duties. Well cooked and warm food is very essential to health and the maintenance of moral force. It is well known how the physical condition affects the moral condition.

The provision of supplies is perhaps the most serious duty lying on the Governor. Doubtless it is a great military virtue to know how to bear privations, but then it is necessary that these privations should be the result of the force of circumstances, and not of a bad administration, ill-placed parsimony, and want of foresight. Anyhow, it is a military virtue which should not be relied on, and it is necessary to take every precaution to ensure the soldier being always fed and kept provided with all he wants; much more can then be demanded from him.

Beside the artillery and engineer, and ordnance store supplies, usually obtainable only from the Government factories and workshops, the supply to be provided comprises food of various kinds for men, forage for the transport and the slaughter animals, solid and liquid fuel for all kinds of heating and lighting purposes,† and a whole host of various other objects.

The history of every prolonged siege shows the vast importance of taking the greatest care to provision a place with regard to both quantity and quality.

As regards quantity, the supplies must be calculated for the total number of people and animals to be fed for a period exceeding the probable duration of the siege, for much of the provision may deteriorate, be stolen, or destroyed.

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* This now more or less obsolete word is used here to distinguish between the commissariat or supply and the transport work of the Army Service Corps.

† Cooking, heating water, raising steam in engines, manufacture of gas, lighting of lamps, etc.

As regards quality, all provisions should be of the standard that the soldiers of the garrison are accustomed to, and should give variety. A certain amount of a better class of food is required for the sick and convalescent.* We ought not to expect troops to feed on dead horses, donkeys, cats, dogs, rats, and mice, or on boiled skins, leather, and even corpses. The honourable feeling that induces the soldier to support all privations, surmount all fatigues, and sacrifice his life, should not be degraded and sullied by his being forced to take part in deeds of barbarism and cannibalism.

There is no need to make anything but a superficial search in history to find out that the most frequent cause of the capitulation of fortified places is the want of food. Metz, Paris, and Plevna all fell from this cause, even though after great privations had been endured. And it will be seen that in most cases the same faults have always been made, viz.: (1), imagining that the fortress could not be attacked so promptly as events proved could be done; and (2) numbers of troops and civilians were at the last moment shut up in the fortress, for whom no provision had been made. Large places cannot be provisioned rapidly. Time is required for this, and the amount of provisions collected should be such as will meet unexpected heavy calls on it. Fortresses near the frontiers should be provisioned, even in peace time, with such stores as are but slowly perishable, the peace garrison gradually consuming them, and their being as gradually replaced by fresh stores. Wars, nowadays, are rapidly carried out, and important and decisive battles will quickly follow one another; and for an unprepared nation, one great check to this rapid advance is the resistance of the frontier fortresses, and this resistance can only be ensured by an adequate provisioning being assured, and that for a sufficiently long duration of siege. Many Continental writers think that a year's supply should be provided, but such a prolonged land warfare could hardly occur on English soil in view of our insular position. In any case, it is better to have too much than too little food. We must always allow for losses from waste, fire, theft, deterioration, etc., and for unexpected consumption arising from the arrival of defeated troops, prisoners of war, passing troops in real want of food, etc. And whatever steps may have been taken to make the civil population lay in food and fuel for themselves, and to prevent the population of the surrounding country from taking refuge within the fortress, yet after a certain time it will be found that aid will have to be given to them.

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* Or fresh meat can be kept for the sick, and salted, tinned and dried foods for those who are in good health.

The supplies collected should also be placed under shelter from the enemy's projectiles, from fire, from deterioration, and from theft and waste. The store-houses should, when possible, consist only of a cellar, and a ground floor of little height. These store-houses should be built as far as possible of inflammable materials, and should be separated from one another so as to prevent a fire in one spreading to the others. Pits can be used for the preservation of certain supplies, such as grain, potatoes, roots, rice, peas, etc. Succulent fodder for transport and other animals can also be preserved for a very considerable time in silos. Luxuries such as coffee, tea, sugar, pepper, salt, vinegar, tobacco, etc., should always be collected in ample quantities. Great care must be exercised in selecting the sites for storing combustible matters and in their storage.

The herds of cattle destined for food must be kept in good order, and so must be fed, watered, kept clean, and, if possible, sheltered from the weather. Regular yards and sheds must be constructed for these with proper drainage, and regular cattlemen and watchmen appointed to feed and water the cattle and to prevent their being stolen.

Further, in order to have fresh vegetables in the place, at any rate for the hospitals, all gardens should be cultivated as kitchen gardens by the gardeners living in the garrison.

Of late years, the introduction of refrigerating or cold storage chambers, sterilized milk, canned and dried foods, fruits, and vegetables, etc., has done away with the necessity of keeping and feeding and watering large herds of live stock for food and milk, and procuring forage and grain for them. But we can only gain this advantage if the proper measures have been taken in peace time.

The ample provision and safe storage of fuel (*e.g.*, coal, wood, oil, etc.), for cooking, heating, and drying, as well as for workshops, engines, etc., is also a vital point; and further, in case gas or electricity should fail, means for lighting streets and houses, whether by candles, lamps, wicks, oil, matches, etc., must be collected and stored.

The commissariat department has thus a very heavy task laid on it to gather supplies of all kinds in adequate quantities—

flesh, flour, biscuit, vegetables, straw, hay, roots, tea, coffee, sugar, salt, pepper, milk, tobacco, coal, wood, etc. Many of these can be in the form of tinned, salted and dried provisions, and milk can now be supplied sterilized for the sick, and which will keep for months in that form. But many departments would have their own stores of coal, etc., for their own special work, *e.g.*, the workshops and gas works under the engineers, the workshops for the transport and artillery, etc., which will relieve the work of the commissariat department to a corresponding extent.

If the civil population has to be fed from the commissariat stores, arrangements will have to be made for this, either by opening shops from which they can purchase the things they require, or by issuing regular rations at various centres without payment. This latter system seems to be the fairest, as the civil population are suffering the perils and discomforts of a siege for the benefit of the nation. But whatever is going to be done in this respect should be decided on in peace time, and adequate arrangements made to meet it.

15. *The Ordnance Store Depôt.*—The work in the ordnance store depôt will be heavy. These stores have to be obtained from the Government manufacturers, contractors, and arsenals before the place is invested. But as constant repairs of the war materials in use will be required, this depôt should have the necessary workshops for carrying out these repairs. The work of repairs is one requiring the employment of trained men, and it is best to collect in these workshops, during the siege, the armourers of the different units. It must not be forgotten that ample quantities are always required of such stores as matches, pipes, rope, string, drawing instruments, paper, ink, pens, pencils, etc.

16. *The Clothing Department.*—In a besieged place a special clothing department would have to be established, which would arrange for the large supply of clothing, socks, blankets, buttons, and boots required during the siege, and for repairs. Cloth, linen, flannel, leather, thread, needles, etc., will have to be procured and stored in ample quantities. This department might also be made to undertake the washing, mending, and darning, etc., of clothes. For these purposes the necessary workshops for tailors and bootmakers, and washhouses with drying places, would have to be arranged for.

17. *The Shelter Accommodation for the Soldier.*—It is very important to try and procure for the soldier the greatest amount of comfort possible, as well as to endeavour to lighten his duties. For this purpose it is necessary that *every* soldier who devotes his person and life to

the defence should find a lodging capable of sheltering him from weather and projectiles. When these conditions are not fulfilled the troops soon come to an end of their physical strength, and lose all their moral force. To divide the garrison into three equal parts, one for duty under arms, one for fatigue duty, and one for repose, and then to only provide shelter for the last named third has been proposed by some unreflecting writers, who evidently are unacquainted with the true conditions of a soldier's life during a siege, for fatigue duty cannot last for 24 hours without interruption. To get the best results it is indispensable to arrange that, as far as possible, the same man will always have the same place, and this for several reasons, amongst which are that it enables the soldier to make himself comfortable, enables better hygienic care to be observed and the shelter to be kept clean, facilitates control, and prevents the development of contagious diseases. It must be remembered that the soldier on returning from many of his duties comes back quite tired and overexcited by the dangers he has just been through, and all should be done to restore him to his normal condition. The different kinds of shelter that can be made use of are (1) bomb-proof casemates; (2), barracks; (3), tents or huts; and (4) private houses.

Bomb-proof casemates are not, as a rule, sufficiently numerous to do more than provide for the artillerymen working the guns near them. Field casemates are not bomb-proof, but they can often be placed in positions where the enemy cannot see them, and who, therefore, will not try to hit them. The wars of 1870–71 and 1877–78 show the absolute necessity of a very large provision of bomb-proof cover, if even only strong enough to resist the splinter of bursting shells.

Barracks are of no use as a protection against shells, and are only safe when built in or near the town, out of reach of the enemy's projectiles, and are not of too large a size. But barracks are not usually built for accommodating the war strength of a garrison.

When tents or huts are used for giving shelter to the troops, they must be placed where the enemy cannot see them. But their location may be betrayed by deserters, spies, or by the replies obtained from prisoners. White tents should never be used; they should be stained or tarred. Encamping troops is to be avoided whenever possible.

The worst way of putting the soldier under shelter is to billet him on the inhabitants, for he is then usually badly lodged, and continually hears wishes expressed for surrendering the fortress, and his chief's orders continually blamed, while he is also frequently exposed to all the seduction of revolutionary politics. Further, the maintenance of control over billetted soldiers is very difficult. Consequently the best way to make use of private houses is to turn the inhabitants out of a suitable block of houses, billetting them on other inhabitants, and then organizing the emptied houses as barracks. This is also perhaps the best of the various means usually available for sheltering the soldier, when sufficient bomb-proof cover is not available for all. If any number of the inhabitants have been expelled from the town (see p. 295) then there will be no difficulty in obtaining house shelter for a considerable portion of the troops.

18. *The Hospital Accommodation for the Sick and the Wounded.*—The medical work during a siege is a very important subject indeed, for the work will be a very heavy one, and the moral of the troops will depend very much on how it is carried out. In past sieges many times more men have died in hospital than in action on account of bad organization, and for want of proper shelter, food, medicines, doctors, etc.; a collection of sick and wounded under such circumstances almost always breeds fevers, epidemics, etc.* Before everything, it is necessary to separate the patients according to their diseases, which means the establishment of at least three or four distinct medical centres—one for contagious diseases, one for serious wounds, one for light wounds and men only slightly ill, and one for other cases, such as itch, venereal, etc. In addition to this, reserve hospitals are required in the event of its being found necessary to cleanse and disinfect the buildings of any one of the other hospitals. Further, special hospitals are required for civil prisoners and prisoners of war. It is very important, as the wars of late years have shown, that the hospitals should be placed in places safe from being injured by the enemy's projectiles; in many cases bomb-proof cover has had to be provided for them, but these are hard to ventilate properly.†

From a hygienic point of view, several smaller hospitals are better than a big one. But each of these hospitals require both male and female help—men to do the hard and unpleasant work, and women to do the nursing, cooking, etc. If we study the accounts of the sieges of the past, the number of patients that have to be cared for at one time may, in a siege, amount to one-third of the garrison. Consequently we see that a good hospital organization in a fortress requires a considerable *personnel* and collection of *matériel*, which must be prepared for in peace time, like most things in war. On the military doctors will fall also the responsibility of procuring, before the appearance of the enemy, a full and ample supply of all the medical stores, drugs, disinfectants, bandages, and comforts likely to be required for the probable duration of the siege.

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* See Appendix I., p. 311, for the worst case of the effect of an insufficiency of hospital and medical arrangements that the writer has met with. The accounts of the sufferings of the Turkish sick and wounded in Plevna, 1877, are also very heartrending.

† The conditions which siege hospitals should fulfil are, according to General Von Kamptz: (1), they should be sheltered from the direct and vertical fire of the enemy; (2), be incombustible; (3), have only a cellar and ground floor; (4), have their accessory buildings isolated from them; and (5) have their doors and windows provided with iron shutters or gratings to protect them from projectiles.

Besides the hospitals, there will have to be formed the first dressing stations, and ambulances and stretcher-bearer companies for bringing in the sick and wounded from the front, that have already been spoken of.

So important is this hospital service that whatever belongs to it should be submitted to a strict and severe supervision. This supervision should be first exercised by the Governor and, under him, by a Board of Health, which will be referred to again later on (see p. 304).

The clergy and officers should be allowed at all times to visit the men. It is very necessary indeed that officers should make it a point of honour to have at all times the greatest solicitude for those under their direct command, and for this reason they should always visit their men's quarters before and after they have gone to rest, and also visit them when in hospital, or in prison, etc. For the care that an officer takes in the welfare of his men, and in sparing them all possible privations, awakens and strengthens their confidence in him, and forms an indissoluble tie between them in time of danger, while at the same time it is a powerful means of preventing abuses.

19. *The Disposal of Dead Persons and Animals.*—The proper burial of dead persons is of the greatest importance to the health of a besieged place, and it is very necessary to organize a service for the burial of the dead and to control this service rigidly.* During the continuance of the siege, all burials, civil and military, should be carried out as quietly as possible. Lists of the dead should be made out and sent to the Town Major † for register. Burial places are also

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* See Appendix I.

† An officer on the staff of the Town Commandant (see p. 303).

required for dead animals; but, if possible they should be cremated, and all garbage and slaughter-house refuse burnt as well. Much subsequent sanitary work is saved by disembowelling dead animals and burning the entrails only; the bodies of the animals need not then be buried so deeply. If any of the burial places cause disease from putrid exhalations, then there must be no hesitation in applying caustic lime to the graves at the time of burial, or even in carrying out the cremation of the dead. In the late Chitral Campaign, portable incinerators were used with success for burning the bodies of dead animals and camp refuse.

20. *The Sanitation of the Place.*—Here again is a subject of the greatest importance.* It includes everything affecting the health of the soldier—the state of his person and clothing, his quarters, his food, his surroundings, the disposal of sewage and garbage, etc. This work must be entrusted to a Board of Health, whose duty it will be to inspect at any time the housing of the troops, the hospitals, the quality and quantity of food issued and supplied, the feeding of the soldiers, the preparation of their food, the water supply, the latrines and sewage systems, the slaughter-houses, the arrangements made for burials, etc. The constant inspection of the latrines and the water supply is especially necessary. In fact, the Board must have complete powers of inspection and recommendation, and should be allowed to directly communicate with the C.R.E., or with an officer detailed by him, for the immediate carrying out of their recommendations. Their powers will extend to the civil population as well, and to all the workmen employed in various works. They must be given a free hand to criticize anybody and anything in matters affecting the sanitation of the place. The Board of Health would have to employ inspectors, who should be men well known about the town, for the inhabitants have as much interest as the troops in having all orders relating to sanitary matters rigorously attended to.

21. *The Work of Disinfection, etc.*—Diseases of an epidemic nature usually break out in besieged places, and, therefore, it is very essential to organize a service for disinfecting, purifying, thoroughly cleansing the clothes, linen, and camp materials used by the diseased persons, and even for burning these things if the means first stated are not sufficient to render them harmless. The disinfecting establishments should be numerous and separated; each hospital should have one. They must have access to water.

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* See Appendix I.

22. *Bathing Places.*—Also, the health of the soldier is affected by the cleanly or uncleanly state of his person, and consequently, when possible, bathing places should be provided for the prevention of skin epidemics. In winter, warm baths can be arranged for in the tanks of dye works, breweries, etc., if the water and fuel be available.

This and other like matters would fall under the supervision of the Board of Health.

23. *Municipal Engineering.* — The maintenance of the municipal roads, streets, sewers, electric-lighting, gas works, water supply, etc., will all have to be carried on during a siege, and must be under the control of the C.R.E., or one of his officers. The maintenance of the gas works requires the collection of sufficient coal or oil to last for the siege. The gas works should be within the place to be defended, for the same reasons that railway stations should be (see p. 270), and so placed that the buildings are protected from direct fire. But if the gas works are likely to be struck by the enemy's projectiles and be set fire to, they become an element of danger, especially if they happen to be near any powder magazine or provision stores. In such a case the works should be removed to a safer place, even if it entails a smaller production*, and the use of gas in houses limited. If the gas works have to be closed, then the streets and houses will have to be lit by oil lanterns, and the apparatus and supplies for these must be secured in time, and organized arrangements made for the necessary cleaning, lighting, etc., of these lamps. The practicability of the streets is always of great importance with regard to the defence of a besieged place, both as regards the movements of troops and transport vehicles, and the facility with which help can be given in case of fires. Houses near ramparts should always be demolished, to prevent the men on the ramparts from being injured by the splinters and stones that fly on houses being struck by projectiles, or from being driven from the ramparts by a conflagration of the houses.

24. *The Extinction of Fires.*—In sieges, the extinction of fires is a very important subject to arrange for, and as the possibility of fires during a siege is now-a-days constant, a number of fire brigades must be organized and kept in a constant state of readiness. The men should be provided with ladders, saws, and axes. Water

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* Small machines for manufacturing gas from oil are nowadays easily procurable in the market.

should be placed in casks or buckets in *every* house by the householders, and fire-posts should be established in different parts of the town, and in sufficient numbers. If possible, these posts should be connected by a system of telegraph lines or other means of signalling, so that they can readily communicate with the fire-engine centres. During a bombardment, detachments of firemen should patrol the streets and enter any house into which a shell is seen to fall, in order to extinguish at once any fire it may have started, by means of the water already placed in the house and their axes, etc.

25. *Balloons.* — Every large fortress should have facilities for manfacturing balloons, not only for the purpose of observing the enemy, the movements of his troops, the progress and emplacement of his works, and for the observation of the results of artillery fire, but also for establishing communication with the outside world in case of complete investment.

26. *Homing Pigeons.*—To make the balloon service of greater value, it is necessary to supplement it with a homing-pigeon service. The homing pigeons inside the fortress would be taken out of the besieged place in the balloons, and would bring back communications from the outside world. Hence it is a wise policy to encourage the establishment of lofts for homing pigeons at places far distant from the fortress and in connection with it, so that messages can be sent in at any time from the outside when the ordinary means of communication are cut. There would be no difficulty in connecting London with Chatham, Portsmouth, and other places. Of course, on the approach of the enemy, all the homing pigeons in the fortress would be taken charge of by the military authorities for the use of the defence and sent to other places, in order to prevent unauthorized information being sent out by disaffected persons to the enemy or his agents. Homing pigeons from distant places would have to be collected for sending information out of the fortress.

27. *Photography.*—But the homing-pigeon service would be of but little real use without the aid of photography for reducing the correspondence and dispatches to a microscopic size. During the siege of Paris, 70,000 words were included in the photographed despatches brought in by pigeons. These microscopic despatches were enlarged, thrown on a screen by magic lantern, and then copied out for delivery.

28. *The Administration of Law and Justice.*—As soon as the enemy approaches the fortress, or, as some say, as soon as war is declared,

the Governor will proclaim "a state of siege" or rule by martial law. This means that the civil law is suspended for the time being, or, at least, is made subordinate to the military, and is placed under the authority of military power. It will undoubtedly lead to the best results to leave the civil magistrates to deal with the civil offenders, so long as these do not commit acts endangering the safety of the defence of the fortress. For such offences there should be a permanent military tribunal, for it will be almost impossible during a siege to form a fresh court-martial for each new offender or batch of offenders.

29. *Civil Police.*—On the state of siege being declared the control of the civil police is taken over by the military Governor, who would assure their independence and increase their numbers from the civil population. The duty of this police is to check any wrong-doing in the town and to prevent all unsanctioned assemblies of the people. The only assemblies that should be permitted are those for divine service, or which are authorized by the Governor. The police should make out a complete list of the people connected with the town and its vicinity, showing their ages, occupations, and dwelling places. The public-houses and inns should be closed, as also all places of an immoral or doubtful character, as it is to these localities that spies find their way and gain information. The police also will assist in seeing that the sanitary precautions for public health are carried out. In the police work is included the care of the prisons and the prisoners in them. The civil prisoners can be employed in cleaning the streets, latrines, and sewers, and other municipal work of a hard and unpleasant kind.

30. *Printing Press and Press Censorship.*—A special press censorship must be established; in fact, it would be a wise plan for the ordinary press to be suppressed, and for the Governor to publish daily during the siege a paper for giving out the facts and information that he wishes the people and troops to know, and for informing the public of the regulations and measures to be adopted for the general interest. The press censor should be a military officer, who alone would know the military value of any particular piece of news or information.

31. *Secret Police.*—Military history shows that it is very necessary to have a secret police in every besieged place. They must be formed and begin their work as soon as the state of siege is declared. They will watch all persons suspected of being wanting in patriotism, all societies, especially their leaders, and all strangers, travelling merchants, etc. This should be done without these people knowing it,

and their correspondence should be opened and read, and if of no great harm sent on, so that the replies may also be read. They should recommend the evacuation of houses belonging to suspected persons, and also of the upper stories of any houses from which signals could be made to the enemy. The secret police must also work among the troops to discover any beginnings of mutiny and their instigators, and also the cause of any desertions; they must also report any indiscreet remarks made by officers and responsible persons on the subject of the weakness of the fortress, want of food, of ammunition, etc., so that these functionaries can be warned.

32. *Military Police and Provost Establishments.*—The military police and military prisons would be maintained during a siege to deal with military prisoners. These military prisoners can be employed, under guard, in carrying out any requisite engineering works, such as earth works, road work, etc., or in assisting in the handling of heavy stores in the parks and depôts, etc.

33. *Intelligence Department.*—It is only in the nature of things that a garrison cannot endure, without impatience, being shut up in a fortress and completely isolated from the outside world. Consequently the greatest efforts should be made to keep up or to establish communication with the exterior. Before the place is completely invested, this can be done by means of reconnaissances, patrols, and well-affected persons; by these means also very exact intelligence of the enemy and his movements are often obtained. But the difficulty is to procure news after the complete investment has been effected. The facilities offered by balloons and homing pigeons have already been pointed out, but as all obtainable news is of the highest importance to the defenders, as it often determines their procedure, it will also be necessary to employ spies and emissaries to get news, to make the secret police open all letters, and to interrogate prisoners and deserters. Spies will be found everywhere, for there is no place in which the allurement of gain will not produce men capable of doing anything. But to be well served in this respect, spies must be very liberally paid, while a hold is kept on their families and possessions as a precaution. Emissaries are individuals who perform the same services, not for money, but for patriotism or through hatred of the enemy. History shows many cases of spies and emissaries successfully passing to and from a besieged place. Experience has fully demonstrated the necessity of having recourse to secret police and spies; both of these are as disagreeable as necessary, and are only tolerated to ensure a great good.

Communications with the outside world may be established by secret telegraphic communications, buried underground or sunk in the beds of streams. These should be prepared in peace time, but it is very probable that the besiegers will dig or drag for them. Streams can be used for floating down with the current bottles, etc., containing letters. But the besiegers will probably spread nets across the stream above and below the place to prevent this means of correspondence.

Visual signalling can also be made use of in many cases, for, from suitable points, it can be worked over intervals of 30 or 40 miles on a sunny day by means of the heliograph. For this reason all the clock towers and spires in a besieged fortress will be closed to all but authorized officials.

The clock towers and spires would also be utilized for observing the enemy and his movements. The observing officer should know the neighbouring country well, so as to be able to send accurate reports. Photographs taken from towers will also afford much useful information. Observations must be made night and day; at night time the observer notes all he can when the electric light plays over the ground or when star shells are fired periodically. Noises as well as sights must be noted.

All this intelligence work should be organized by an Intelligence Department, which collects all the information it can from every possible source. The secret police and spies should be under this department, as well as the press censorship and service of homing pigeons. The head of the Intelligence Department should know how to keep silence, and should enjoy the whole confidence of the Governor.

34. *Use of Cyphers.*—The cypher to be used between the Governor and the military chiefs outside the fortress should be decided on in peace time. The key to the cypher should be known only to the Governor and to the head of the Intelligence Department.

35. *Organization of Special Signals.*—The Governor should establish certain signals, sound or visual, to give warning at moments of danger. The signals should be very simple, such as rockets or coloured fire, ringing of bells, sounding bugles, drums, etc. These may be used to warn or call up the inhabitants as well as the troops. They may also be used for calling up reinforcements to certain places. Hence we see the necessity of only allowing authorized persons to enter towers containing bells, for the latter should only be sounded by order of the Governor.

36. *Means of Providing Money.*—During a siege money always becomes scarce, although it must be in the place somewhere. It becomes hoarded. When this happens different steps have been taken to meet the difficulty, as it is very conducive to maintaining a healthy moral feeling that the troops and the military and civilian employees should receive their pay regularly. The plate obtained from jewellers and rich people may be melted up and coined, or paper money issued, after all the money held by banks or rich people has been obtained on loan. The credit of the paper money should be guaranteed by the Governor and the leading bankers and merchants, etc., and it should be redeemed as soon as possible after the war has ceased.

37. *The Prisoners of War.*—During a siege some prisoners of war are usually made, but a large number of such prisoners may have been placed in the fortress by the field army before the place is invested. It is a great mistake to use fortresses near the frontier for this purpose. The prisoners of war should be humanely housed and cared for, only they should never be kept together, but be scattered about in small groups and separated from their officers. They must be prevented from having access to anyone, for fear of their communicating with the exterior. Some think that prisoners of war should be made to work for their living, a diet of bread and water only being given to those who will not work. Even the officers who are prisoners must be watched with great care and treated with great rigour; they must not be given any freedom during the siege, and all their ornaments and money must be taken from them and given back by degrees, so as to prevent them trying to bribe anyone. Any outbreak among the prisoners of war should be most severely repressed.

38. *The Organization of the Guard Service in the Interior of a Fortress.*—There are many places in the interior of a place, such as the military establishments, supply depôts and storehouses, magazines, etc., that have to be guarded, for on their safe existence depends the power of the place to last out. The guard service includes—

A Guard for each powder magazine.
„ each laboratory.
„ the artillery arsenal.
„ the engineer park.
„ each ordnance store.
„ the gun and shell foundry.

A Guard for the powder factory.
„ the public money chest.
„ each commissariat store.
„ each clothing store.
„ each tower.
„ the gas works.
„ each railway station and yard.
„ the prisoners of war, in prison and at work.
„ the military prisoners, in prison and at work.

As these numerous guards cannot be furnished by the combatant troops without reducing their effective numbers and exhausting them, they should be provided by means of *garrison companies* raised from among the retired soldiers residing in the town and its vicinity. They can be commanded by retired officers.

39. *The Care of the Keys.*—The guardianship of the numerous keys, of varied form, that are required in a fortified place should be carefully thought out and arranged for, so that there may be no loss of time in getting a key when required. Many cases have occurred in history where the attackers have succeeded in entering the works of the place at the same time as the repulsed defenders, because the latter were not able to close the gates of the communications. It is very certain that much order and method are required in the distribution and guardianship of the keys, in order that they may always be at hand to open or close the entrances to forts, buildings, passages, bridges, barriers, keeps, blockhouses, guard-houses, caponiers, escarp and counterscarp batteries, subterranean communications, magazines, laboratories, dams, posterns, mouths of sewers, gratings, etc. The custody of the various keys should be carefully laid down, and also the rules for ensuring their being found rapidly when required. The principal keys of a detached fort should be held by the fort commander himself.

40. *The Clergy in a Besieged Fortress.*—The clergy will always exercise a considerable influence on the people, and consequently the attitude that they take during a siege is not a matter of indifference. If their attitude is prejudicial to the interests of the defence, the Governor should be informed of it, for it is easier to combat an open enemy than a hidden one who hides his secret thoughts under the mask of friendship. At the commencement of the siege, the ministers of all persuasions should be summoned by the Town Commandant,* in

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* The officer appointed to control the town (see p. 298).

the name of the Governor, and ordered to allude to the state of the town in their next sermons, and to inculcate into their congregations blind obedience and submission to the military authorities of the fortress and town. It is even a good plan to give the clergy one or two selected texts to use for their sermons, which latter should be reported on by the officers sent to listen to them, in order to see if the sentiments of the clergy are loyal or not. The clergy should also be requested to make public prayer for the troops employed on duty and in the defence of the place. They should be constantly reminded of the duty of visiting the sick and wounded and prisoners, and each clergyman should be given a written permit by the Town Commandant, allowing him free access to the hospitals and to the prisons for this purpose.

The Organization of Civilian Labour.—From what has been said concerning the different kinds of work that have to be performed in carrying out the defences of a besieged place, we see that a very large proportion of it can either be entirely carried out by civilians, or in which civilians can assist, and if this be done, then the troops will be enormously relieved. This gives rise to two reflections: (1), how far is it right to employ the civilian population in works required for the defence ? and (2), if they are to be so employed, for what kinds of work should they be taken, and how should they be organized for the purpose ?

We will take this second question first, assuming for the time being that it is a right principle to employ the civilian population as far as possible.

A slight consideration of the different varieties of works to be carried out will show that all these kinds of work can be placed, more or less accurately, under three heads, viz. :—

1. Those executed under conditions of constant danger to the life of the workman.

2. Those executed under conditions of only occasional danger to the life of the workman.

3. Those executed under conditions of no danger to the life of the workman, so far as there can be no danger in a besieged place.

The *first class of works* consist of those carried out directly under the fire of the enemy. All such works must naturally fall on the troops themselves, and military history teaches us that the best defences have been made where the troops understood not only the use of their arms, but also of the pick and shovel.

Under the *second class of works* we may place the transport and handling of materials and supplies of all kinds sent to the front, the collection and removal of the wounded to the rear, the service of the powder magazines and laboratories, the manufacture of powder and explosives, and the extinction of fires. We may perhaps also add the service of the railway, tramway, canal, river, telegraph, telephone, etc., communications. In all these kinds of works civilians and requisitioned transport can be usefully employed, and for this purpose should be organized into regular units, be clothed in distinctive dresses, and be placed under control and discipline under the command of selected officers and N.C.Os. These organized units would be distributed to the various services as required.

Keeping the troops in the front line supplied daily with all the ammunition, food, and other supplies that they may require necessitates an immense amount of work, and it is easily seen that the troops of the garrison would soon be worn out by such heavy work, if called upon to do it. Consequently the communication work between the depôts in rear and the fighting lines should be very largely performed by civilian workmen (such as porters, navvies, drivers, etc.) and requisitioned transport organized in the way already described. It is very probable that local contractors and other employers of labour and local foremen of works can be usefully employed in commanding and directing the work of such organized labour and transport units.

In every celebrated siege recorded in history the combatants have not been charged with the conveyance of the wounded from the scene of fighting, and the necessary stretcher-bearer companies required for this work should be raised and organized from among the civilian population.

Powder magazines and laboratories require, as has been pointed out, the work of specially trained men. But these men can be assisted in all their heavy work (such as the handling of heavy barrels of powder, and boxes of cartridges, etc.) by picked steady civilians, permanently told off to assist them. As to the manufacture of explosives, that can be, as in peace time, entirely carried out by civilians directed by a military officer.

The work of extinction of fires has usually, in most sieges, been left to the inhabitants, and the fire brigades, already mentioned, should be raised and organized from among the civilian population, though they must be placed under strict military control.

Again, in all the railway, tramway, waterway, and electric communications there is ample scope for the employment of a large number of civilians, and all messenger services can also be carried out by them.

Consequently for carrying out the second class of works we want to raise and organize into regular units or companies a large number of civilians, with distinctive dresses, as follows:—

(*a*). Labour companies.

(*b*). Transport companies with vehicles and draught animals.

(*c*). Stretcher-bearer companies with vehicles and draught animals.

(*d*). Fire brigades.

The labour companies would be permanently detailed for employment to the various departments as required. The men and vehicles and animals employed in each special kind of work should in addition to their general distinctive mark, have a special distinctive mark indicating the special duties that they have been permanently detailed for.

As regards the *third class of works*, they include all those not mentioned above. But a few comments on the nature of the labour required for them is necessary.

In the first place there is no necessity for these kinds of works to organize the workmen required for them into regular companies, but these employees must, nevertheless, be enrolled and told off to each special kind of work, and be made to understand that their daily attendance at stated hours is required and will be enforced.

The cooking of food before being sent out, if this work is adopted, and the washing, mending, darning, making and repairing of underclothing and clothes for the troops and organized auxiliary companies can be best carried out by women, who have a greater aptitude for this kind of work than men.

Women can also be employed in nursing the sick and wounded. In this sphere of work they cannot be approached by men, while the patients do better and recover quicker when being looked after by women nurses. The heavier and unpleasant duties connected with the care of the sick and wounded should, however, be performed by men, such as the removal and disposal of bodily evacuations, the carrying of patients, etc. In the hospital work the military doctors can be ably assisted by the civilian doctors in the place.

For the above purposes the women of a besieged place should be enrolled as well as the men, and have their respective duties allotted to them before the appearance of the enemy. The women who are not told off to such special duties will find ample employment in providing for the wants of the unorganized civil labour.

For the making of heavy clothes and boots, and their repairs, the civilian artizans who follow these trades should be selected and enrolled, and made to work under military guidance.

As regards the repair of warlike stores under the ordnance store department, there is much that can be done by civilians of suitable trades (gunsmiths, leather workers, saddlers, etc.), who would be detailed for this work under the direction of the officers and N.C.Os of the Ordnance Store Department.

Again, in the artillery and engineer parks, and in their attached workshops, a very large number of civilians, tradesmen and labourers can be employed, both as workmen and foremen.

The Commissariat Department affords a wide field of usefulness for the employment of the local civilian butchers, bakers, millers, farmers, grocers, etc., who should be carefully enrolled and told off to these duties with foremen placed over them.

The interment of the dead—both as regards men and animals—is a service that can well be carried out by civilians under a responsible head. Perhaps the best way to carry this service out is by means of a committee, presided over by the Town Major, and whose members would include some of the clergy, a doctor, and some prominent civilians. Some of the committee should attend every burial.

The Board of Health, which inspects and controls all the sanitary matters connected with the fortress, both as regards the troops and the civil population, will require a certain number of inspectors, who should be well-known civilians.

As regards the ordinary engineering works connected with the town itself, it will be best to leave it to the local civil engineers and specialists and their employees, who have been employed on them during peace time, viz., turncocks, scavengers, chimney sweeps, etc. The only thing required is to ensure that the necessary work shall be done at once when required, and consequently these civilians should be under the control of the C.R.E., or one of his officers told off for the purpose.

The balloon construction, the care of the homing pigeons, and the photographic and printing work of the fortress can all be left in the hands of trained civilian specialists, who must, however, be under military supervision.

Any increase to the civil police must naturally be raised from among the civil population. The secret police also would be raised from the same source.

The guard service would be carried out by the enrolment and organization into companies of retired soldiers commanded by retired officers.

Consequently, for the purpose of carrying out the third class of works, we want to enrol and definitely detail a large number of civilians, both men and women, to certain specified kinds of works. These need not be definitely organized into regular companies, nor clothed in a distinctive dress. We also want to raise and organize and arm a sufficient number of companies of retired soldiers, commanded by retired officers, for the guard service of the fortress.

Thus we see that only two classes of civilian workmen are required, viz.: (1) those who are organized into companies and placed under military discipline for semi-dangerous works; and (2) those who are only enrolled and detailed to special kinds of work, not entailing any danger. The former should receive a considerably higher rate of pay and remuneration for their services than the latter.

In addition to this work of enrolment, and organization of men and women, and allotment of specific duties to them, it must be clearly borne in mind that it is equally necessary to erect, organize and equip the workshops and stores in which they are to be employed under supervision, whenever the necessary buildings, with equipment, are not to be found locally in the possession of civilian manufacturers, etc. These workshops and storehouses, if they have to be erected, should be scattered, so as to prevent the enemy's projectiles being able to do any great damage in any particular locality. And this dispersal of workshops and stores can be usefully effected by giving each department (artillery, engineers, ordnance store, commissariat, transport, clothing, etc.) the workshops and storehouses required for their own wants. This prevents the delays and friction that always occur if one department has to do any kind of work for another department. In peace time, centralized work may be more economical, financially speaking, but in war time true economy is to be found in decentralization and the smooth working of the military organization and machinery.

It may here be remarked that it would be very advantageous that as much of the above-mentioned preparations and works as possible should be carried out in peace time, in order to lessen as much as possible the work to be done, both during a siege and while hurriedly preparing for it.

From the foregoing it will be seen that the administrative works; that have to be performed during a siege, afford so many means of finding remunerative employment for the civil population of the place, and of relieving the troops from the burden of such works. In many cases the civil and military prisoners and prisoners of war can also be advantageously employed on them. In some sieges, however, the civilian employees, whose services have been utilized in the administrative departments of the garrison, have been guilty of many grossly fraudulent acts, but it may be pointed out that such acts have only occurred from want of a proper organization and surveillance of the civil labour employed.

It may be here added that civilian labour can be very largely used before the siege begins in carrying out all the preparatory works that have to be done, clearing the field of fire, throwing up works, etc. For this purpose, labour can be procured from the surrounding country, but this extra labour should be dismissed before the investment is effected, or else it means that more useless mouths will have to be fed during the siege.

The Necessity for Employing Civilian Labour.—As to the justice of the principle of thus forcibly employing civil labour to relieve the troops of the garrison as much as possible of all the work that has to be done, it may be objected that the organization of these auxiliary bodies of men, vehicles, and draught animals will impose too considerable an obligation on the town and its vicinity; but we must remember that in every defence, every resource, as well as every force at our disposal, must be utilized with the greatest energy if success and a victorious end to the struggle is really desired. All half measures, all weakness, are here fatal, and even if success appears doubtful, it would be simply insanity not to do everything possible to assure victory. Besides this, such an organization, far from imposing too heavy a charge on the civil population of the besieged place, would really be advantageous to them, because it would assure to the poorest part of the population both subsistence and profit during the rigours of siege, and prevent their being sent away, while at the same time they are prevented from giving themselves up to intrigue, which might prove hurtful to the defence of the place. And such a use of auxiliary workmen will enormously relieve the troops and render them always available for fighting. Further, the moral effect of such an organization on the workmen enrolled is by no means to be despised. Every enrolled workman will have faith in success if he sees the defence of the fortress well prepared. Consequently such an organization forms a powerful means of interesting the civil population in the defence, and so of giving a greater amount of energy to it. But it is very necessary to prepare this organization before the enemy appears, so as not to lose time in carrying it into effect. The rapidity with which the auxiliary corps enter into their work is a visible proof to the civilian population of the care with which the defence has been prepared. This rapidity will also serve to raise the courage of the defenders, and will minimize the difficulty, naturally caused by a sudden appearance of the enemy, of withdrawing into the place such of the surrounding population who may be required for the defence.

The Surveillance of the Civilian Workmen during a Siege.—This question is one of considerable importance, and it is well to place all the civil employees under a special head, who, with a subordinate staff, would be charged with the inspection and control of these employees. Some kind of distinguishing mark or uniform should be given to auxiliary companies of workmen, for by this means obedience is more easily obtained, and the workmen should be made to feel that they will share in the honours and fate of the troops; if the fortress falls they will be prisoners of war; if it resists successfully they will be given the same advantages and honours as the troops.

As a check on some of the work of the civil workmen and contractors, the distribution of supplies of all kinds should be made in the presence of an officer, who certifies to their quality and quantity.

The Powers of the Governor.—The existence of a state of siege should be notified by the Governor publicly. It applies not only to the garrison but also to the civil population of the town and its environs. The military Governor takes into his own hands all the civil and military powers of the place, though the civil authorities as a matter of convenience should be allowed and encouraged to continue to do all such of their work as is not taken over by the military authorities. The civil population should be made to thoroughly understand this, and that they have now passed from civil law to martial law. The limits of the garrison and of the town should be made known, and marked with sign posts, accompanied with the information that no one can pass the outer limits without a pass.

The Expulsion of Unprofitable Inhabitants.—As *all* the civilian population are not required to aid in the defence, either directly or indirectly, but only those who can be of use, morally and materially, there should appear, with the declaration of the state of siege, the order of expulsion of all those who cannot aid in the defence—people without homes and under police surveillance, all suspected strangers, agitators, occupants of brothels and houses of ill-fame, vagabonds, idlers, lunatics, strangers, and those who cannot afford to collect sufficient food or fuel for the siege, or who are unable to work for them during the siege. This list should have been prepared in peace time with the aid of the civil authorities, and no hesitation must be shown in expelling everyone (even the rich) who are known to be ready to agitate the people and foment disorder. All old men, old women, children, *enciente* women, and sickly people should be made to quit the place out of kindness to them, but provision should be made for them elsewhere—a point that must always be considered.* When once the investment has been completed, the enemy will not allow anyone to be sent out of the place. This course of action is quite a proper one, for the enemy desires the fall of the fortress by any means, and the more people there are to feed and to frighten inside it, the sooner the place will fall. As regards those who wish to leave, the right of free exit cannot be allowed in the interest of the defence. All public functionaries, firemen, civil engineers, contractors, telegraph employees, photographers, printers, and artizans of all kinds, *e.g.*, mechanics, builders, carpenters, joiners, etc., must be compelled to stay, and also men who possess influence among the people, such as the clergy, doctors, and other professional men who can be utilized during the siege. It is only after we have considered the works that have to be done during a siege that we can properly understand the necessity for restricting the right of free exit and entrance.

The French regulations order that the families of the Governor and of the Council of Defence (see p. 301) are to be sent away from the fortress as soon as the state of siege is declared.

The Governor's Precautionary Measures.—The chief duty of the Governor is to see to the immediate provisioning and arming of the fortress, to place the garrison on a war footing, and to take all the other necessary measures required for the carrying out of a stubborn defence. He should seize all the large buildings, hotels, places of amusement, mills, breweries, distilleries, slaughter-houses, etc., that can be of use to the defence as storehouses, workshops, hospitals, etc. He will order the levelling and demolition of such suburbs and houses that will hamper the defence in any way or favour the enemy.

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* See remarks on p. 306.

The Treatment of the Civil Population.—History has shown in many cases that the enemy can make active allies in a fortress, especially by sowing discord between the civil population and the troops. Consequently as soon as the state of siege has been declared, the inhabitants must be called on to deposit all their arms and ammunition, flags, trumpets, etc., at the Ordnance Store depôts. The same precaution must be taken as regards gunsmiths and iron merchants, who possess materials for making arms. This step is necessary to avoid having two armed forces side by side in a fortress, and thus preventing a possible cause of disturbance. All homing pigeons will have also to be given up.

A loyal feeling on the part of the civil population is one of the elements that contributes largely to the duration of the defence, for it forms a powerful stimulus to raise and strengthen the courage and confidence of the troops. Consequently everything should be done to strengthen the loyalty of the inhabitants, and to maintain it as long as possible. A powerful means of doing this is to establish a strong moral bond between the troops and the inhabitants by making the one dependent on the other. A garrison can never free itself from the assistance of the civil population, for it cannot do everything itself, and if it has to force the inhabitants to work, troops will be required for this, causing a reduction of the number of troops available for fighting. Consequently the Governor and everyone under him should seek to establish a good feeling between the troops and the inhabitants.

From the beginning the Governor, even if not having at first entire confidence in the population, should so act as not to let them think that he mistrusts them. They should be made to understand the object of all the wise measures taken with regard to them, and it might be well if the Governor placed the mayor of the town on his staff, and made him his mouthpiece to the inhabitants on ordinary occasions. Trust in the civilians can be shown by accepting volunteers to serve with the artillery and infantry, but these should not be formed into separate bodies, but be attached to the existing battalions and batteries. The mere fact of enrolling and organizing civilians to assist in the various auxiliary services (such as auxiliary workmen for transport, artillery, and engineers, stretcher-bearers, superintendents of works, police constables, firemen, hospital employees, etc.) will enlist the sympathies of the population.

If the Governor cannot trust the inhabitants, he must, during the whole siege, have in readiness energetic means for suppressing all revolts. Cavalry patrols are the best for preventing crowds collecting, and if cavalry and infantry are not sufficient, there must be no hesitation about using artillery. In such a case the inhabitants must be kept away from the defensive works, and prevented from speaking to the troops on duty. It is by far the best plan to have everything ready to stifle any attempt to revolt, and to subdue it energetically in case it breaks out. The troops required for protecting the military buildings, the stores, and the communications from an attack in force, should be told off beforehand.

The preliminary signs of a coming revolt cannot escape an observant Governor, who ought not to allow himself to be deceived by the civil authorities in this matter. Those officers and military employees also who are in daily contact with the populace, and also the police, cannot fail, unless utterly incapable, to discover any conspiracies that may be hatching. But all reports on such matters should be carefully received, for we must always remember that gross exaggerations may arise from the intemperate zeal of those informers who are stimulated either by patriotism or the allurement of a reward.

From the commencement of the siege the populace should be informed that the troops have the formal order to use their arms on the slightest resistance.

The inhabitants should also be clearly made to understand that absolute obedience on their part to all the regulations ordered to be observed by the Governor is necessary. Amongst these regulations it should be stated that every inhabitant who goes out at night must carry a lighted lantern, and that at any night alarm in the town every house is to have its windows lighted up; also that no one is to change his residence without permission.

The Proposed Organization of the Military and Civil Services for Carrying Out the Defence.—The Governor's dictatorship over the fortress and its environs, including the civil population, confers on him duties so numerous and extended that it is impossible for him alone to cope with the task, for he has, in addition to these, to direct the military operations of the defence. This last duty exacts so much time, energy, work, intelligence, and force of character, that besides the C.R.A. and C.R.E., he should have on his staff an Officer Commanding the Troops. These three officers are individually responsible for the preservation of the fortress, and they determine on the plan of defence under the direction of the Governor.

As regards the organization of all the rest of the works to be done, it should be carried out on the basis of leaving all the details to officers who act as the Governor's deputies; and he will only intervene personally in the various branches of the administrative services in order to exercise the supreme direction, and decide finally, after having taken the personal opinions of his assistants.

A siege is only a prolonged battle, and consequently we see, especially after what has been said in the foregoing pages, that the *rôle* of the town that is being defended should be that of a base of supply for the troops fighting outside of it. Consequently this base should be put under a distinct commander, who would be called the *Town Commandant.* He should have complete charge of the town (the limits of which should be defined), and be given a sufficiently strong armed force to enable him to carry out his duties.

As regards the military organization, the line of detached forts, *i.e.*, the main line of defence, is divided up into sections, according to the natural accidents of the ground, facility of communications, etc. The garrison proper is also divided up into the same number of parts, though the strength of the various sub-divisions will not necessarily be the same, and each part will be allotted to the section for which its strength has been calculated. A separate commander will be appointed to each detached fort and section. The actual number of troops placed in the different sections depends on the relative importance of each, and their relative advantages and disadvantages for battle purposes. If the sections are too large in extent, their respective commanders cannot exercise an efficient control over them; if they are too small in extent, then the transmission of orders is rendered more difficult, and the control of the Governor is weakened. The troops in each section are divided up into

1. Outposts.
2. Working parties.
3. Fatigue parties.
4. Section reserves.
5. Garrisons for the detached forts.

Of these, the first four sub-divisions will relieve one another periodically. Besides these, there will be

6. Special reserves (when necessary) for reinforcing specially dangerous points.

7. A general reserve or mobile field force.

8. Guard troops for guarding the town, and for maintaining order in it.

The guard troops for the town will be placed under the command of the Town Commandant. The special reserves (if any) and the general reserve should be placed under distinct commanders, as these reserves are either for a special use or for temporary use on any portion of the line of defence. In a very large fortress the general reserve may be grouped into two or more distinct bodies, each under its own commander, and each with an allotted sphere of action.

All these various commanders will have command over all the arms and services working within the limits of their respective commands, and each should be given a sufficient number of staff and departmental officers suited to the magnitude of the work to be done. Thus every section should have its artillery, engineer, medical, and supply officers, each under a local head. The fort and section commanders should be supplied with telegraph operators as well, if they are in telegraphic communication with the Governor's head-quarters. Then there will be in rear in the town, or in its vicinity, the great parks or depôts of the artillery, engineers, supply and transport services, and also the hospitals—all under the Town Commandant. Between these and the front will be the communication service—railway, tramway, roads, canal, river, telegraph, telephone, etc.—which should also be placed under the control of the Town Commandant to ensure its efficient working with the supply depôts and parks in the town.

As regards the organization for the administrative services, they fall into two categories—

1. The Governor's staff, for fighting purposes.

2. The Town Commandant's staff, for administrative purposes.

The Governor's Staff.—The Governor would naturally have on his staff the O.C. the Troops, the C.R.A., and the C.R.E.

1. The O.C. the Troops should be of such a rank as to be the second in command, and ready to replace the Governor should anything happen to him. With the Governor's approval, he would direct all the offensive operations of the troops of the garrison, especially such enterprises as aim at hindering the enemy's march and disputing the approaches, as well as the execution of all sorties.

He decides the outpost line, while satisfying the demands of the section commanders when these demands have been found to be well-grounded. He should have on his staff a sufficient number of staff officers, A.D.Cs, and orderlies, for his work, besides clerks.

2. The C.R.A. is the Governor's adviser on all tactical and technical questions concerning the artillery. He also is reponsible for the work of the artillery park, and of the gun and shell and the powder factories, and has charge of the magazines and laboratories. It is his duty to decide on the measures to be taken for arming the works in accordance with the plan elaborated during peace time. In conjunction with the C.R.E. and the Governor, he decides on the positions for the batteries to be constructed. He arranges for the distribution of the ordnance at his disposal, and assigns to various batteries their *rôle* in the fight. He issues the necessary orders for the nature of the fire to be employed so as to prevent waste of ammunition, and arranges for the replacing of the latter as it is expended. It is his duty to made the necessary reconnaissances for finding out the intention of the attackers, and to prepare to meet them; and he should also decide where he wants the ground lit up in front at night by means of the electric light, when this is available. He must keep a daily journal of his operations, in which should be entered the expenditure of guns and ammunition, and he should be able to give each day to the Governor an exact report as to the state of the artillery *matériel* in his charge. He has under his orders some of the organized companies of civilian workmen and of transport. He requires a sufficient number of assistants and clerks for all this work.

3. The C.R.E. is the Governor's adviser in all tactical and technical questions concerning the work of the engineers of the garrison. He is also responsible for the due efficiency of the engineer park and its workshops, the railway service, the telegraph service, the general water supply, and for the provision of tools, material, and labour required for the various works. He should make a daily reconnaissance of the works of the attack to try and ascertain what the attackers are next going to do, and try and carry out the C.R.A.'s wishes with regard to the electric search light for enabling the artillery to fire with effect at night or to allow of a watch being kept on the enemy's movements and works. He should keep a daily journal of all that takes place in his department, and be able to give the Governor each day an accurate report of the state of the *matériel* in his charge. Under his orders are placed some of the organized

companies of civilian workmen and of transport. He requires a large number of assistants and clerks to enable him to carry out his multifarious duties.

4. Besides these three officers the Governor should have on his staff the officer in charge of the Intelligence Department. This Intelligence Officer has to collect and examine all the reports that are sent in, and to submit his conclusions to the Governor. This officer should have under his orders all the observing towers, the balloons that have been made and aëronauts, the spies, the secret police, and the homing pigeon service. Under him also should be placed the photographic service, the printing press and press censorship. He draws up and issues all the official intelligence, regulations, appeals to the public, etc., that the Governor thinks necessary to publish. He makes out the correspondence in cypher. For all these purposes he requires a suitable staff of officers and clerks.

Besides the above, some minor staff officers, A.D.C.s, clerks, telegraphers, and orderlies are necessary to complete the Governor's staff.

The minor staff officers are required for carrying out the Governor's correspondence, and for keeping up the daily journal of the defence, in which is entered all the military dispositions taken for the safety and defence of the fortress, as well as all events that may influence the defence.

The Governor should also be in close connection with the mayor of the place. In fact, it would often be advisable to make the mayor an honorary member of the Governor's staff, not only from the good effect it would have on the civil population, but also from the possibility of using the mayor as his intermediary with the townspeople for many purposes. The Governor can explain to the mayor the reason and objects of his measures and regulations, and then allow the mayor to explain these to the populace.

The Governor alone should have power to replace, on account of incompetency, any of the officers who have been appointed to any command or to any position on the staff.

In order to ensure obtaining support and counsel, the Governor should form two *Councils of Defence*, which he will assemble whenever he considers necessary.

The Special Council of Defence would be composed of the Governor as president, and the O.C. the Troops, the C.R.A., the C.R.E., and the Intelligence Officer as members.

The General Council of Defence would be composed of the above officers, and also of the Town Commandant, the President of the Board of Health, the heads of the various arms and administrative departments, and the section commanders. But this would not prevent the Governor ordering the heads of any of the special or minor services (such as the chief of the police, etc.) to be present to express their opinions, without, however, their taking part in the deliberations.

The Special Council of Defence would only deal with the military affairs of the fortress, and as a siege is only a prolonged battle, this Council would only be composed of combatant officers and the officer who supplies the intelligence that they have to work on. The General Council of Defence would only deal with the administrative affairs of the fortress. But it must never be forgotten that the Governor alone is absolutely responsible for everything that is done. And, consequently, the *rôle* of the above councils can only be (1) to act as a means of informing the Governor accurately of all that is going on, and of all that is required to be done; and (2) to act as a means of enabling the Governor to inform his subordinates of his aims and objects, so that all may work together to a common end.

It is always the Governor alone who decides at last. This prerogative and responsibility is indispensable for unity of aim and the exercise of authority. There is only one recognized exception to this rule, viz., when the Governor considers that a capitulation is necessary. In such a case, even when the want of provisions and of means for continuing the defence appears to justify this extremity, the consent of those who compose the Special Council of Defence must be obtained as well.

It is important to let every member of the above councils know that the Governor will bear the full responsibility of all that is done. If this is not the case the greater part of those called to the council will attend with the fixed idea of compromising themselves as little as possible by any expression of their real opinions. This explains why so many councils of defence in past sieges have been remarkable for the timidity of their decisions. No person summoned to a council meeting should arrive with the idea that the Governor finds himself in a critical position, and that he wishes to hear some advice of which he can make use, in case of non-success, to cause his responsibility to be divided with others, or even to try and throw it on them entirely.

The true use of a Council of Defence is to enable the Governor, by the advice of its members, to convince himself that his own opinions are well founded, and are not too rashly conceived in view of the means at his disposal.

The Town Commandant's Staff.—In all business not directly connected with the military defence, the Town Commandant is naturally the Governor's deputy. His *rôle* is a double one, combining the duties of an officer commanding the base, and of an officer commanding the line of communications. He commands the guard troops placed in the town, and is responsible for giving all the necessary facilities required for the execution of the various indispensable administrative services, whose headquarters should always be located within the limits of his command. Under him will be the treasury, the various supply services and their employees, (artillery and engineer parks; the gun, shell and powder factories; and the commissariat, ordnance store, and clothing departments), the hospitals, stretcher-bearer companies, the fire brigades, the civil and military police and prisons, the prisoners of war, the military guards, the administration of martial law, the sanitary condition of the place, the disposal of the dead, the arrangements for divine service, the municipal engineering, and the gas works, the control of the civilian workmen variously employed in organized companies or otherwise, the supervision of the requisitioned transport service, the working of the communications (rail, etc.), telegraphs, etc., and all other duties that may arise.

To enable him to efficiently carry out these multifarious duties, military history shows that it is very necessary to exercise a minute control over those employed in the administration, and to indissolubly bind their lot with that of the fortress. Consequently it is only reasonable in the interests of the defence that all the employees of the administrative services should be subordinated to the authority of the Town Commandant and his assistants, as the only way of impressing a single impulse to all the parts of this great war machine, and to ensure that no regulation or order is lost sight of, or altered, or spoilt from negligence, indolence, or narrowness of mind.

The Town Commandant requires several assistants to carry out the various duties entrusted to him for execution. These duties should be divided up and placed under the charge of responsible heads. These may be as follows:—

1. The Town Major would control the garrison companies and guard service, the civil police, all prisoners and prisons, including

prisoners of war, turnkeys, the fire brigades, burials, divine service, the clergy, etc. He would, in fact, undertake the entire administration of the place, and see that all the regulations ordered by the Governor are carried out.

2. The Board of Health has duties of the highest kind to perform. Its President should be an experienced and energetic retired officer of high rank. This Board should have free power to go everywhere, and visit every place—the places where the troops are housed, the hospital, the supply depôts, the cook-houses, washing places, disinfecting places, burial places, bathing places, canteens, workshops, cattle lines, stables, slaughter-houses, etc.—and report on their sanitary condition, on the quality of the food and cooking, on remedial measures required to be taken, etc., etc. The President of the Board should have power to correspond directly with the executive officers of the medical, veterinary, and engineer services and with the Town Major, with a view to a rapid and prompt execution of the recommendations of the Board.

3. The municipal engineer will have charge of all the engineering, sanitary, water, and lighting works in the place. His technical head is the C.R.E.

4. The officer in charge of the commissariat would have charge of the supplies of food, forage, fuel, etc., of all kinds and of the slaughter cattle yards. He would also arrange for the cooking of all food issued (if such a course is decided on). If he has no transport told off permanently to him, he will apply to the officer in charge of the transport to send what is required.

5. The officer in charge of the ordnance store also undertakes the repair of all war material, and has charge of the necessary workshops and artificers.

6. The officer in charge of the clothing department also takes charge of the washing and repairing of clothes and boots.

7. The principal medical officer has charge of all the hospitals, and their accessories, and of the stretcher-bearer companies. He should also be made responsible for the disinfecting service.

8. The officer in charge of the artillery park has charge of the workshops connected with it, and the civilian workmen employed therein. His technical head is the C.R.A.

9. The officer in charge of the engineer park has charge of the workshops connected with it, and of the civilians employed in them. His technical head is the C.R.E.

10. The director of railway communications has charge of the

yards and workshops and civilian workmen required for the efficient execution of his duties. His technical head is the C.R.E.

11. The director of telegraphs will be in charge of all the electrical communications and of the workshops required for the repair and maintenance of this service; his technical head is the C.R.E.

12. The superintendent of the gun and shell factory; his technical head is the C.R.A.

13. The superintendent of the powder factory; his technical head is the C.R.A.

14. The superintendent of the balloon factory.

15. The officer in charge of transport will have charge of all the animals and waggons assembled at the transport stations, and he will promptly execute all orders received for the conveyance of stores and materials. He will have organized companies of workmen to assist him.

16. The principal veterinary officer will be responsible for the sanitary state and health of the draught and slaughter animals in the place.

17. The paymaster in charge of the treasury chest makes all the payment for the various departments and issues money to them for wages, and collects the receipts. Frequent inspections of the treasury chest are necessary to check any thefts.

18. The president of the standing court-martial will have to try all civilians or soldiers who disobey the orders issued by the Governor or any of his deputies, who force sentries, who excite discouragement or discontent, or who do prejudice in any way to the defence of the fortress.

19. The superintendent of civil labour, who will be responsible for investigating all cases of absence from work, and for ordering the police to bring the delinquents up for punishment if necessary.

In addition to the above officials, the Town Commandant and the heads of the various departments under him will require a certain number of staff officers, clerks and orderlies to carry on their correspondence, and to keep up their respective daily journals, account books, store ledgers, etc.

The above proposed organization* gives a definite responsibility to each of the authorities in the fortress who may have anything to do with the defence of the place and the administration of the town.

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* This organization is only a suggested one. Someone may probably be able to suggest a better one now that the subject is brought forward.

By such an organization, by the creation of garrison companies and of auxiliary companies of workmen and stretcher bearers, and by the adoption of all the other measures suggested, the soldiers and the civilian population of the place will be led to firmly believe in the durability of the resistance. This confidence, which can only be established by means of the minute measures of precaution taken for the defence of the place, can only engender in the one and in the other the conviction that the place will successfully resist the enemy's efforts to capture it. If this conviction is deeply rooted in the hearts of the defenders, success will not fail to crown their combined efforts.

It is not in the province of this paper to consider if the existing laws of the country are such as will give the Governor of a fortress the full powers required to carry out effectively the enormous responsibility laid on him, and to rise to the high level of the national duty he has to perform. But this point should be seriously considered and provided for, if necessary, by Parliamentary legislation. However, it may be stated that a French engineer officer, Lieut.-Colonel F. Prevost, has pointed out that some of the chief causes of the rapid fall of the French fortified places in 1870–71 were (1) the presence of a large and useless civilian population, which often clamoured for capitulation directly a bombardment took place; (2), the absence of a sufficient amount of bomb-proof cover, not only for the troops, but also for the stores, hospitals, and civil population; and (3) the absence of sufficient preparations and an inadequate supply of provisions and stores. Most of these places, it may be said, were not provided with outlying detached forts to keep the enemy's batteries at a distance from the town. And, in order to reduce the demand for bomb-proof cover, and the amount of supplies to be collected and the danger arising from the presence of an unemployed and easily excited unprotected civil population, Lieut.-Colonel Prevost demands that the laws of the country should formally order the expulsion of all useless mouths from a besieged fortress, and that a daily allowance should be made by the Government for the support of those who have been thus expelled for the benefit of the defence. He also advocates an indemnity being given to those civilians who have been wounded during the defence, to the families of those civilians who have been killed, and to the owners of any property that has been damaged during the siege. Such legislative prescriptions, he considers, would have a very great influence in ensuring the best conditions for the execution of a good defence.

In the foregoing pages, no special effort has been made to emphasize any one part of the suggested preparatory measures more than another. But it may be here pointed out that even a slight acquaintance with the history of past sieges will show the necessity of laying special emphasis on the following points :—

(*a*). The early and adequate provision of all kinds of supplies (warlike, food, water, fuel, clothing, etc.) for the troops and civil population in a fortress likely to be besieged.

(*b*). The employment of the civilian population in a besieged fortress on administrative works.

(*c*). The expulsion of every person from a fortress on the point of being besieged who cannot assist, directly or indirectly, in its defence.

(*d*). The provision of ample bomb-proof cover for the purpose of shelter and hospital accommodation.

(*e*). The provision of adequate measures for the extinction of fires* and the disposal of the dead bodies of men and animals, etc.

(*f*). The employment of a secret police as a check on hostile spies, correspondence with the enemy, conspiracies, revolts, etc. during the siege.

Concluding Remarks.—On page 265 it was stated that the defence of every fortress should be conducted in such a manner as to draw on to itself the greatest number possible of the enemy's troops. This object can be most effectively attained by making the troops of the garrison as free as possible for offensive action, and it has been the purpose of this paper to show how this can best be done by relieving the troops of nearly all the administrative work, *which has to be done by some one*, and employing civilian labour in their place for this essential duty. In fact, it may be asserted that the absolute necessity for so employing the civilian population in a fortified place has been clearly demonstrated for the purpose of keeping them from spreading discontent among the troops, and so demoralizing them.

The best conditions for enabling a prolonged and stubborn defence have been sketched out in the preceding pages, but, as Marshal

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* See Appendix II. This subject is so important that Napoleon used to make special reference to it in the "Letters Patent" he issued, when appointing a Governor to a fortified place. Fires during a siege are usually due to the shells of the enemy's bombarding batteries. The moral effect of a bombardment is always very considerable on the civilian population, and it is important to prevent it being added to by a serious material effect.

Vauban has pointed out, during a long peace those most concerned in the provision of these conditions often forget that the fortress may some day or other be besieged, and thus do not pay any attention to them. The rapidity and ease with which the majority of the French fortresses fell in 1870–71 affords a striking example of the disastrous effects of inadequate and one-sided preparations, of timid or unexperienced Governors, and of insufficient garrisons in respect to both quantity and quality.* The preparatory measures that have been suggested only afford the means for subsequent vigorous action. This should be clearly remembered. They are nothing in themselves. They only afford favourable conditions for a defence, and as such have a most powerful influence on the conduct of the defence.

Now supposing the above organization to have been effected, and the necessary supplies and transport collected and stored for the proper defence of the fortress, what next? *Industry* having played its part in *affording favourable conditions* for the defence, and for making the fortress play an offensive *rôle*, it now remains for valour to make use of these favourable conditions. Industry alone is of little value, and valour alone is also of little value. If nothing has been collected or prepared, then the greatest valour shown in the defence cannot prevent starvation; if there is no valour shown in the defence, the greatest accumulation of stores and administrative ability possible cannot prevent the fall of the place. What is required is industry and valour combined, and it is only when they are usefully and adequately associated that the best results are obtained.†

The first condition for a good defence, both as regards valour and industry, is an experienced, determined, and brave Governor. This fact is verified again and again in military history. One of the chief causes of failure of fortresses has been a weak or timid Governor, who has failed to rise to the height of his duty, or to comprehend the necessity to maintain the defence to the last moment possible, in order to make the fortress play its proper *rôle* in the war. Other causes of failure have been too small a garrison, absence of discipline and training among the defenders, insufficiency of armament and of ordnance, or of food or water supplies, etc. But such causes are usually chiefly due to a defective peace preparation, though a good Governor can do much to minimize these effects.

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* See *The Siege Operations in the Campaign Against France*, 1870-71, by Von Tiedemann (translated by Major Tyler, R.E.), and *Les Forteresses Françaises pendant la Guerre de* 1870–71, by Lieut.-Col. F. Prevost. Both of these works afford ample illustrations as to the value of many of the preparatory measures that have been advocated.

† The ideas contained in this paragraph have been taken from Carnot's *De la défence des Places fortes* — a work that should be studied by every officer in the army if he wants to learn the principles that should underlie the defence of a fortified place. This work was written by order of Napoleon I. for the benefit of the French officers of all arms, and it was so widely read that copies of it were found in almost every place that had been occupied by the French during their disastrous retreat from Russia in 1812.

However, *the standard rule for the defence of every fortress must be* NEVER TO CAPITULATE SO LONG AS MEN, MATERIAL, AND SUPPLIES LAST OUT. There is but one exception to this rule that has been admitted by some military writers, viz. :—When the outer works of the enceinte or central locality have been carried by assault, as well as any interior entrenchments that have been thrown up to localize the effect of any such successful assault, then before the last of the interior entrenchments is assaulted a capitulation may be arranged for, in order to procure favourable terms for the civil population of the place. But Napoleon I. would not allow even this exception, as this can be seen by the orders he issued to the officers he appointed as Governors to his fortified places.* And it is probably to these or similar orders that the Duke of Wellington alludes, when, in his despatch of the 10th September, 1813, announcing the capture of the castle of San Sebastian, he says, "Under the ordonnance recently issued by the French Government, the difficulties of the operations of a siege, and the length of time it must take, are greatly increased, and they can be brought to a conclusion only by the storm of the breach of the body of the place."

The enemy on first appearing before a fortress will summon the garrison to capitulate, and will often accompany the summons with the most direful threats. When this happens it must be remembered that history shows that the usual cause of such threats is the inability on the part of the enemy to carry out a regular siege, and that the threats are only an effort to so intimidate either the Governor, the garrison, or the civil population, or all three together, as to cause the immediate surrender of the place.

We have lately read the accounts of the defence of Chitral, and we have justly given due praise to the gallantry displayed by all concerned. But, after what has been considered in this paper, it will be readily seen that, on account of the wise measures adopted for the internal administration of Chitral, and which undoubtedly largely contributed to the duration of the defence, an equal amount of praise should be accorded to the common sense shown by the officer conducting the defence and his associates. Engineer officers should especially accord this praise, for they will always have a large part to play in all defences, both in administrative and executive capacities, and they should always bear in mind Napoleon's reply, when he was asked what special qualifications are required of an engineer officer: "That rare virtue, common sense." The administrative requirements, both as regards supply and organization, of a fortress are, as we can see, but matters of common sense, and it may be the duty of any engineer officer, whose special duty it is to consider such matters, to advise the Governor of a fortified place on all matters relating to or affecting its efficient defence in every respect.

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* See Appendix II., which gives two examples of "Letters Patent" issued by Napoleon I. to two officers whom he appointed as Governors to Sas de Grand (1809) and Antwerp (1809) respectively.

And once again let it be repeated that the guiding principle of every defence should be: "Never to capitulate so long as any means, however small, for continuing the defence exists." We may quote, on this point, the example of Marshal Fabert, who said: "If, in order to save a fortress, entrusted to me by my sovereign, from falling into the hands of an enemy, it were only necessary to place on the breach myself, my family, and all I possess, I should not hesitate one instant." Another example to be imitated is that of the brave D'Essé de Montalembert, who, even when very sick, undertook the defence of Thérouanne at the request of his king with these memorable words: "Sire, with a brave and loyal heart I fly to my post. I have heard that the place is ill supplied, has no entrenchments, and is not even provided with what is necessary to repair the works. Nevertheless, when you hear that Thérouanne is taken, then be assured that D'Essé is cured of his sickness, and is dead." And so it came to pass, for he was killed on the breach, by a musket shot, during the assault.

The value of one's life is to be measured not only by what is accomplished during its duration for the benefit of one's country and humanity at large, but also by its motive principles. Life is nothing in itself; only death can fix upon it its proper value; and the defenders of our fortified places should determine, each and all, that death, should they fall, should stamp their lives as "well spent." Then, and then only, will they rise to the level of their high duties.

APPENDIX I.

THE BAD EFFECTS OF AN INSUFFICIENT PROVISION OF SANITARY, MEDICAL AND HOSPITAL SERVICES.

THE defence of Torgau in the winter of 1813 is perhaps the worst example that can be produced of the frightful effects that can be caused by an insufficient provision of sanitary, medical and hospital services. The French troops enclosed in Torgau not only suffered the greatest privations, but were also attacked by an epidemic that caused such terrible ravages in their ranks as probably cannot be equalled in the history of human calamities.

The privations of the garrison were added to by continual reductions being made to the rations, in order to make them last out, and even horseflesh had to be very sparingly issued towards the last. Torgau was naturally an unhealthy place, being situated between the river Elbe and large marshes; the water was of very bad quality, being hard and irony, and would not cook vegetables properly, which produced an aggravated diarrhœa. The inhabitants had a bad habit of collecting manure (stable and human) in their yards, which had no drainage. This added to the unhealthiness of the place. The Governor issued orders about the necessity of the town being kept clean, but apparently nothing was done to enforce them, which would have required force, as the inhabitants were in sympathy with the besiegers, and were not willing to relieve the garrison of any kind of work. The population consisted of about 5,000 souls.

The troops in Torgau were composed chiefly of the convalescent men and malingerers of nine different corps of the Grand Army; these were organized into companies and battalions. Up to the 19th October, 1813, 2,327 men had died, and on the 20th October the garrison (24,650 men) was composed of 15,904 combatants, 1,346 non-combatants, and 7,400 sick and wounded. To accommodate these latter, the inhabitants of 82 houses had been turned out, and the town hall, the wheat granaries, the "Château," part of the supply magazines, and the loft over the royal stables had been turned into hospitals. The existing hospitals could scarcely accommodate 2,000 sick.

In November an average of 250 deaths *per day* occurred in the hospitals, and the garrison was reduced on the 20th November to 17,142 men, composed of 9,682 combatants, 1,271 non-combatants, and 5,189 wounded or sick, giving a reduction in the garrison of

7,508 men in a month; of these 7,089 died in the hospitals, and 419 were killed in action or had deserted. On the 24th December the garrison consisted of only 9,500 men, with 3,083 sick. And on the 10th January, 1814, when the place capitulated for want of food, there were only 8,334 men in the garrison, with 3,188 sick. The total deaths that occurred from September, 1813, to the 10th January, 1814, was 19,269, while 938 more died after the siege was over.

These frightful losses were almost entirely due to an epidemic, which took two distinct forms—diarrhœa or dysentry and typhus. The diarrhœa caused the greatest mortality. The discharges from the body had a corpse-like odour. It chiefly attacked the men who had been worn out by continual marching, with night bivouacs, during a very rainy period, and who had been very badly fed at the same time. The effect of the bad water in the place has already been noted. The inhabitants who had laid in ample food supplies for their own use, and who were relatively well fed, were hardly attacked at all by this complaint.

While the diarrhœa attacked and destroyed the weak, young soldiers, enfeebled by fatigue and miseries, the typhus, on the other hand, attacked the stronger and more robust men. It was the same in the town; the old people and children were spared, while most of the victims of the typhus were people of both sexes between the ages of 20 and 45 years.

The effect of the position of the cemetery being exposed to the enemy's fire was that burials ceased to be carried out, and, the Governor not being able to prevent this, the consequence was that the corpses were placed anywhere in the streets, on the ramparts, in backyards, etc. Luckily, a very intense cold froze the bodies, or else the epidemic would have been far worse. Many of the bodies were thrown into the Elbe. After a while a large working party of soldiers had to be taken off the works to bury in earth and quicklime some 900 bodies that had been collected.

The effect of the epidemic and the privations of the garrison was to knock all the life out of the men, who became listless and went about with a carelessness that bordered on the most absolute stupidity. All sympathy for the sufferings of others seemed to disappear in them. The actual cause of the epidemic, apart from the bad feeding and fatigues of the soldiers, was due to the crowding of a great number of individuals into confined places where the air could not be renewed, the dampness of the locality, and the want of cleanliness in the town. The atmosphere in the town was simply reeking with animal emanations. Towards the end of the siege, Torgau itself was nothing but a vast hospital. At every street there were to be seen dead bodies that had been thrown from the windows.

The description given by the German doctors of the state of things they found, when the fortress capitulated, is almost incredible :—

"The hospitals had become at Torgau veritable caverns of death. It had been found necessary to place the unfortunate soldiers so close to one another that they almost touched. Straw for lying on was wanting, as well as utensils, instruments, medicine, and healthy food. But, in addition to all, order and forethought were wanting. The greater number of the employees, of whom there were many, performed their work badly. Thinking too much of their own miseries, they did not attend on the sick soldiers with all the zeal requisite under the circumstances. It was in vain that the Governor, the noble Count de Narbonne, sought to raise the *moral* of these unfortunate people. His frequent personal visits, which proved deadly to him, produced no effect. The principal character of the disease was a diarrhœa of a corpse-like odour. In consequence of little care and surveillance, the dirt became so considerable that patients struggled in their own excrement and rotted like living corpses. In the hospitals of Torgau it often happened that a patient, consumed by a burning thirst, drank the urine of his neighbour with avidity, being unable to obtain any other drink. The dead often remained the whole day in the same bed, close to their living comrades. The strongest patients snatched from the weakest and the dying their straw for lying on, their blankets and linen, in order to procure some slight comfort for themselves. The greedy and diabolical hands of the hospital orderlies, instead of helping them, ransacked unceasingly the beds of the patients, and long before death had closed their eyes for ever the unfortunate dying man was already despoiled of all he possessed. The ambulances of Torgau were, properly speaking, nothing but immense cesspools. The greater part of the latrines, for which no care had been taken, and into which even the corpses were flung, were full to the mouth. They even overflowed, and putrid urine flowed on the walls and staircases. In the Chateau of Hortenfels each window served as a latrine; human excrements were stuck all over the walls. They formed immense heaps in the courts. In the wards it was almost impossible to open the doors, obstructed by ordure. It was necessary to pass over excrement, and to cross on the corpses, to reach those still living. All the glass had been broken by the bombardment, and as wood failed, it was necessary to take the doors and windows to heat the wards. These poor unfortunate creatures, very badly provided with blankets, found themselves exposed to the most severe cold, as if in the streets; many had their hands and feet frozen. Their drinks even froze beside them. There was not any treatment regularly carried out; even food was not distributed in sufficient quantity. Wood was generally wanted to heat the food, so that the patients received their nourishment quite cold."

In the town of Torgau itself 980 deaths from sickness occurred among 5,000 inhabitants, that is, one-fifth died, while among the troops four-fifths died. This shows the very great influence that good nourishment, housing, and clothing exercise on the health of people.

The accounts of many other sieges also show the terrible results that may arise from an insufficient provision of sanitary, medical, and hospital services. For example, almost about the same time as nearly 20,000 French died during the siege of Torgau, 21,000 French succumbed to disease at the siege of Mayence. But what has been said is sufficient to bring out the extreme importance of a good hospital, medical and sanitary organization.

APPENDIX II.

"LETTERS PATENT" ISSUED BY NAPOLEON I. IN 1809 TO THE GOVERNORS OF FORTIFIED PLACES, AND THE LAWS OF FRANCE, AT THE TIME, ON "CAPITULATIONS."

In conferring on Colonel Le Fosse the command of Sas de Gand, Napoleon issued the following Letters Patent:—

"Napoleon, by the Grace of God, &c., &c.

"Whereas the place of Sas de Gand is threatened by the enemy, we have resolved to appoint, as commander of that place, an officer of distinguished bravery.

"We have taken into our consideration the services of the Sieur La Fosse, colonel; and we have appointed, and by these present lettres patentes do appoint him commander of the place of Sas de Gand.

"We order him to repair instantly to the said place of Sas de Gand, and never to quit it under any pretence whatsoever. We order him frequently to inspect and visit the supplies for the siege, the magazines for the artillery; to take special care that they be abundantly supplied, and sheltered equally from the attacks of the enemy and from the inclemency of the weather. We order him to preserve us this place, and never to surrender it under any pretence whatsoever. He must always bear in mind the inevitable consequences of disobedience to our orders. We order him to run the chances of one assault, in order to prolong his defence and increase the loss of the enemy: and as the reduction of the place must be the last term of his efforts, and the result of an absolute impossibility to resist any longer, we forbid him to accelerate that unfortunate event by his consent, were it but by one hour, and under pretence of obtaining an honorable capitulation.

"We will it, that whenever the Council of Defence shall be called together to consult on the operations, these lettres patentes shall be read, in an audible and intelligible manner."

Given this tenth day of the month of August, one thousand eight hundred and nine, and the sixth year of our reign.

In conferring the command of Antwerp on General Colaud, Napoleon used much the same expressions, adding, however, some additional injunctions.

"Napoleon, by the Grace of God, &c., &c.

"The town of Antwerp being declared in a state of siege, we have resolved to nominate and appoint for its commander a distinguished officer, whose zeal and fidelity has been tried in many actions.

"We have taken into our consideration the services of the general of division Senator Colaud, and we have appointed him, and hereby do appoint him, 'Commandant of the place of Antwerp,' now in a state of siege. Conformably to our decree of the 11th instant, by which he is appointed governor of the said place, we order him to be there by the—————————, and never to go beyond a musket shot of the ramparts of its advanced works; frequently to inspect and visit the provisions for the garrison, and the magazines for the artillery, and to take care that they are abundantly supplied, and secure from the attacks of the enemy as well as from the weather. We enjoin him to take all necessary precautions to increase occasionally the supplies of the place, and also to ensure provisions for the inhabitants, even greater in proportion than those for the garrison. He will employ, within forty-eight hours after his arrival at Antwerp, commissioners, civil and military, to ascertain and certify that the said supplies are actually in the place: he will oblige the inhabitants to provide themselves with buckets, and to keep them constantly filled with water: three inspectors appointed to each street, will make domiciliary visits to see that this order is attended to: he will take care that the engines be in the best possible state; they will be stationed as a sort of reserve, and as much as possible sheltered from the enemy's fire. He will take the necessary measures to augment their number. He will give directions to collect a great quantity of fascines, palisades, and also all the timber for blindages, that can possibly be procured.

"We order him to preserve the place, and never to think of surrendering it on any pretence whatsoever: in case of its being invested and blockaded, he must be deaf to all reports from the enemy. He must equally resist insinuations and attacks, and never suffer his courage to droop. His constant rule must be to have as little communication with the enemy as possible. He will always bear in mind the dreadful and inevitable consequences of disobedience to our orders, or of neglect in the execution of his duties. He must never forget that, in losing our esteem, he incurs the severity of military law; and that this law condemns him, and his staff, to death, if he surrenders the place; even if two lunettes were taken and a practicable breach made in the body of the place. In case the enemy should have blown up the counter-scarp, he must prevent the consequences that might result from this, by intrenching himself in the interior of the bastions. In short, we most positively do order and command him to run the chances of an assault, for the purpose of protracting his defence, and increasing the loss of the enemy. He must recollect that a Frenchman should think his life of no value, the moment it is put in competition with his honour; this idea must be to him, and his subordinate officers, the mainspring of all his actions; and as the reduction of the place must be the last term of his efforts, and the result of total impossibility to resist any longer, we forbid him to accelerate that unfortunate event by his consent, even by one hour, and under pretence of obtaining an honourable capitulation.

"We direct that whenever the Council of Defence shall be called together to consult on the operations, these lettres patentes shall be read in an audible and intelligible voice."

Given this 11th day of August, 1809, and of our reign the 6th.

In conclusion, there is given below an extract of the French laws at the beginning of this century relative to capitulation, and which illustrate some of the topics that have already been considered.

"*Law of the 26th July,* 1792."

ARTICLE I.

Every commander of a fortified place, who surrenders to an enemy, previous to the breach of the body of the place being accessible and practicable, and before he has sustained at least one assault, supposing an interior intrenchment behind the breach, will be punished with death; unless he be in want of ammunition and provisions.

ARTICLE II.

Fortified places being the property of the empire, in no case whatever shall the inhabitants, or civil authorities, require of the commander to surrender; under pain of being themselves dealt with as rebels and traitors to their country.

Law of the 21st Brumaire, year 5, Titre iii.

ARTICLE I.

Every military man, or individual attached to the army, convicted of treason, will be condemned to death.

ARTICLE II.

Those who are considered guilty of treason, 1st, &c., &c.

8th. Every commander of a besieged place, who, without having taken the advice, or against the wish of the majority of the military council of the place (at which council the commanding officers of the engineers and artillery must always assist), has consented to the reduction of the place, before a practicable breach is made, or his having sustained one assault.

"*Regulation of the Directory,* 16 *Messidor, year* 7 *of the French Republic.*"

ARTICLE I.

Every commander of a fortified place who capitulates, without having obliged the assailants to go through the slow and successive proceedings of a siege, and previous to his having repulsed, at least one assault, in the body of the place, will be brought to a court-martial, in order to be tried conformably to the law. This regulation will take place from the beginning of this campaign.

ARTICLE II.

The members of the council of war, who have signed these shameful capitulations, and those who, having a right to assist at the council, have not protested against the measure, will also be tried by a court-martial.

ARTICLE III.

The Minister at War will appoint the members of the court-martial, who will take cognizance of these guilty cases; and he is charged with the prompt execution of this present regulation, which will be inserted in the bulletin of laws.

PAPER X.

LISTS OF

SERVICE ORDNANCE,

WITH DETAILS OF

GUNS, AMMUNITION, CARRIAGES, AND SLIDES.

1.—Breech-Loading Ordnance (B.L. & R.B.L.).

2.—Muzzle-Loading Ordnance (R.M.L.).

3.—Quick-Firing and Machine Guns.

Corrected to March, 1895.

WAR OFFICE.

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1.—BREECH-LOADING

BREECH-LOADING

Ordnance.						Bore.		Chamber.		
Nature.	Mark.	Material.	Weight.	Service.	Total Length in Ins.	Length in Ins.	Length in calibres.	Diameter in Inches.	Length to Base of Projectile.	Capacity in Cubic Inches.
16·25-inch	—	Steel	111 tons	N	524·0	487·5	30·0	21·125	84·5	[illegible]
13·5 "	I	"	69 "	N	433·0	405·0	30·0	18·0	66·5	17100
13·5 " ...	II, IIA	"	67 "							
	III	"								
	IIIA, B, C, D, E, F*	"								
	IV	"								
12 "	I, IA	Wrt.-iron & steel	47 "	L	328·5	301·75	25·14	14·75	55 8	[illegible]
12 "	III, IV, V	Steel	45 "	N	328·5	303·0	25·25	16·0	48·0	[illegible]
12 "	VW	"	46 "							
12 "	VI, VII	"	46 "	L	328·5	303·0	25·25	16·0	48·0	[illegible]
12 " wire...	VIII	Steel and wire ...	46 "	N	445·5	425·15	35·43	16·0	70·0	—
10 "	I	Steel	32 "	L	342·4	317·5	31·75	14·0	54·0	[illegible]
10 " ...	II, III, IV	"	29 "	C	342·4	320·0	32·0	14·0	54·0	[illegible]
	IIIA	"	29 "	N						
†9·2 " ...	I, cI & U.cI	Wrt.-iron & steel	22 "	C	255·8	235·23	25·56	11·0	44·0	[illegible]
	II		21 "	N						
9·2 " ...	III	Steel	24 "	N	310·0	289·8	31·5	12·0	43·0	[illegible]
	V	"	22 "							
9·2 " ...	IV, IVA	"	23 "	L	310·0	289·8	31·5	12·0	43·0	[illegible]
	VI, VIA, VIC	"	22 "	C						
	VIB	"	22 "	L						
	VII	"	22 "	N						

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* One gun only, 13·5-inch Mark III.*, is for Land Service. It is a Mark IIIF. gun with a trunnion band fitted to it.

† Some of these guns for Naval Service have been fitted with latest pattern breech mechanism, with B and D locks and are known as Marks IA. and IIA.

ORDNANCE (B.L. AND R.B.L.).

ORDNANCE (*B L.*).

Rifling.						Venting.	Ballistic Effects.			Ordnance.	
System.	Mark.*	Twist.	Length in Inches	Obturation.	No. of Grooves.		Muzzle Velocity in Foot Seconds.	Muzzle Energy in Foot Tons.	Penetration of Wrought Iron at 1,000 Yds. in Ins.	Nature.	Mark.
Polygroove (Elswick)	II	From 1 in 60 at breech to 1 in 30 at muzzle†	397·2	Pad	78	Axial	2087	54877	32·0	16·25 in....	—
Polygroove (hook section).	II	From 1 in 60 at breech to 1 in 30 at muzzle	333·4	,,	54	,,	2016	35217	28·2	13·5 ,, ... 13·5 ,,	I II, IIA III III A,B,C,D,E,F IV
,,	I	From 1 in 104·5 at breech to 1 in 35 at 124·525ins. from the muzzle; remainder uniform 1 in 35	241·45	,,	48	,,	1914	18137	20·4	12 ,, ...	I, IA
,,	I	From 1 in 120 at breech to 1 in 35 at 126·275ins. from the muzzle; remainder uniform 1 in 35	250·8	,,	48	,,				12 ,,	III, IV, V VW
,,	II	From 1 in 60 at breech to 1 in 30 at muzzle	250·8	,,	48	,,				12 ,, ...	VI, VII
,,	I	From 0 to 1 in 30 at muzzle in a length of 278·95 ins.; the 70·335 ins. at breech end being straight	349·285	,,	48	,,	—	—	—	12-in. wire	VIII
,,	II	From 1 in 60 at breech to 1 in 30 at muzzle	259·68‡	,,	40	,,	2040	14391	20·5	10 ,, ...	I
,,			262·18							10 ,,	II, III, IV IIIA
,,	I	From 1 in 118·5 at breech to 1 in 35 at 81·12ins. from the muzzle; remainder uniform 1 in 35	187·73	,,	37	,,	1781	8406	15·9	9·2 ,,	I, cI, ucI II
,,	I	From 1 in 120 at breech to 1 in 30 at 120·4 ins. from the muzzle; remainder uniform 1 in 30	243·4	,,	37	,,	2035	10915	18·3	9·2 ,,	III V
,,	II	From 1 in 60 at breech to 1 in 30 at muzzle	243·4	,,	37	,,				9·2 ,,	IV, IVA VI, VIA, VIC VIB VII

B.L. guns of 6-inch calibre and upwards for future manufacture, or when repaired with new A tubes, or through-lined, will be rifled with an uniformly increasing twist from 1 in 60 at the breech to 1 in 30 at the muzzle. This system is termed Mark II. rifling.

Except Nos. 1, 2 and 3 guns, which have Mark I. rifling, viz. :—from 1 in 130 at breech to 1 in 30 at 77·2 inches from muzzle; remainder uniform 1 in 30.

The 2·5 inches at the muzzle of Mark I. gun are unrified.

Ordnance.						Bore.		Chamber.		
Nature.	**Mark.**	**Material.**	**Weight.**	**Service.**	**Total Length in Ins.**	**Length in Ins.**	**Length in Calibres.**	**Diameter in Inches.**	**Length to Base of Projectile.**	**Capacity in Cubic Inches.**
8-inch‡	III	Steel chase-hooped	14 tons	N	222·5	201·1	25·1	10·5	34·5	3050
8 ,, ...	IV	Steel	15 ,,	N	254·5	236·9	29·61	10·5	38·0	3350
8 ,, ...	VI	,, ...	14 ,,	N	254·5	236 9	29·61	10·5	38·0	3350
8 ,, ...	VII	Wrt.-iron & steel	12 ,,	L	218·5	204·0	25·5	10·5	38·0	3240
8 ,, ...	VIIA	Steel	13 ,,	L	222·5	208·0	26·0	10·5	38·5	3292
80-pr.	I	Wrt.-iron & steel chasehooped	82 cwt.	N	162·6	153·2	25·53	7·5	28·05	1155
6-inch ... {	III ,,	Steel unchaseh'd ,, chasehooped	89 ,, 5 tons	} N	170·7	153·2	25·53	8·0	26·75	1364
6 ,, ...	§IV, VI	Steel	5 ,,	C	173·5	156·0	26·0	8·0	26·75	1364
6 ,, ...	V	,, ...	5 ,,	L	195·3	183·5	30·58	8·0	31·75	1515
5 ,, ...	II	,, ...	38 cwt.	N	139·5	125·35	25·07	5·75	19·05	504
5 ,, ...	III, IV, V	,, ...	40 ,,	C	139·15	125·0	25·0	5·75	19·05	[illegible]

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‡ 8-inch B.L. guns, Marks I and II, have been manufactured, but have been appropriated for proof of powder, and will not be issued to the Service. Mark V gun has been designed but not manufactured.

§ Some of the 6-inch Mark IV, of later manufacture, have Mark II rifling.

ORDNANCE (*B.L.*).—(*Continued*).

Rifling.							Ballistic Effects.			Ordnance.	
System.	Mark.	Twist.	Length in Inches	Obturation.	No. of Grooves.	Venting.	Muzzle Velocity in Foot Seconds.	Muzzle Energy in Foot Tons.	Penetration of Wrought Iron at 1,000 Yds. in Ins.	Nature.	Mark.
Poly-groove (hook section)	I	From 1 in 120 at breech to 1 in 35 at 63·9 ins. from the muzzle; remainder uniform 1 in 35	163·6	Pad	32	Axial	1953	5552	13·4	8-inch	III
,,	I	From 1 in 110 at breech to 1 in 35 at 99·7 ins. from the muzzle; remainder uniform 1 in 35	195·8	,,	32	,,	2150	6720	14·9	8 ,,	IV
,,	II	From 1 in 60 at breech to 1 in 30 at muzzle.	195·8	,,	32	,,	2200	7046	15·2	8 ,,	VI
Poly-groove (Elswick)	I	From 1 in 100 at breech to 1 in 40 at 6·82 ins. from the muzzle; remainder uniform 1 in 40	162·82	Cup	23	,,	2000	4992	12·8	8 ,,	VII
,,	I	From 1 in 100 at breech to 1 in 40 at 10·82 ins. from the muzzle; remainder uniform 1 in 40	166·82	,,	33	,,				8 ,,	VIIA
,,	I	From 0 at breech to 1 in 40 at 4·02 ins. from the muzzle; remainder uniform 1 in 40	123·02	,,	28	,,	1880	1960	8·5	80-pr.	I
Poly-groove (hook section)	I	From 1 in 120 at breech to 1 in 35 at 58·9 ins. from the muzzle; remainder uniform 1 in 35	124·075	Pad	24	,,	1672§	1938	8·8	6-inch	III
,,	I	From 1 in 120 at breech to 1 in 35 at 61·75 ins. from the muzzle; remainder uniform 1 in 35	126·875	,,	24	,,	1960	2663	10·5	6 ,,	IV, VI
	II	From 1 in 60 at breech to 1 in 30 at muzzle	126·875	,,	24	,,	1870‖	2425	9·8		
Poly-groove (Elswick)	I	From 0 at breech to 1 in 30 at muzzle	149·75	Cup	28	,,	1920	2685	10·2	6 ,,	V
Poly-groove (hook section)	I	From 1 in 120 at breech to 1 in 25 at 52·15 ins. from the muzzle; remainder uniform 1 in 25	104·3	Pad	20	,,	1750	1062	6·25	5 ,,	II
,,	I	From 1 in 120 at breech to 1 in 25 at 51·8 ins. from the muzzle; remainder uniform 1 in 25	103·95	,,	20	,,				5 ,,	III, IV, V

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§ Except with Mark III chase-hooped guns on V.B. and V.C.P. carriages, when ballistics are the same as for Marks IV and VI guns.

‖ With charges of Prism^1 Black and P^2.

Ordnance.						Bore.		Chamber.		
Nature.	Mark.	Material.	Weight.	Service.	Total Length in Ins.	Length in Ins.	Length in Calibres.	Diameter in Inches.	Length to Base of Projectile.	Capacity in Cubic Inches.
4-inch ...	**II, IIP, III IIIA, IV V, VI	Steel ... ... ,, ... ,, ...	23 cwt. 26 ,, 26 ,,	N N C	120·0	108·0	27·0	5·3	18·5	417
4 ,, (jointed)	I	,, ...	25 ,,	Indian	110·8	101·8	25·4	—	—	—
30-pr.	I	,, (4-in. calibre)	20 ,,	Indian	115·0	108·0	27·0	4·2	17·5	250
20-pr.	I	,, (3·4-in. calibre)	12 ,,	L	107·5	98·5	29·0	3·9	15·3	186
†12-pr., 7cwt ...	I	,, (3-in. calibre)	7 ,,	L	92·85	84·0	28·0	3·625	11·0	117
‡12-pr., 6cwt. ...	I	,, (3-in. calibre)	6 ,,	L	66·75	59·0	19 66	3·2	8·35	70
32-pr. S.B.B.L.	I	Cast-iron (6·35-in. calibre)	42 ,,	L	97·6	86·0	13·5	6·55	4·1	136
Howitzers.										
6-inch, 30cwt.	I	Steel	30 ,,	L	94·0	84·0	14·0	6·4	6·7	239
6 ,, 25cwt.	I	,, ...	25 ,,	Indian	82·0	72·0	12·0	6·4	10·2	341
5·4 ,, ...	I	,, ...	12¾ ,,	Indian	62·0	54·0	10·0	5·6	3·4	96
5 ,, ...	I	,, ...	9 ,,	L	49·5	42·0	8·4	5 2	3·2	77

** The addition P to a Mark indicates that the gun has been converted from the system of friction to that of percussion firing.

† When firing 15lb. projectiles, this gun is designated 15-pr., 7 cwt., Mark I.

‡ Formerly known as 12-pr., Q/2.

RDNANCE (B.L.).—(*Continued*).

Rifling.							Ballistic Effects.			Ordnance.	
System.	Mark.	Twist.	Length in Inches	Obturation.	No. of Grooves.	Venting.	Muzzle Velocity in Foot Seconds.	Muzzle Energy in Foot Tons.	Penetration of Wrought Iron at 1,000 Yds. in Ins.	Nature.	Mark.
Poly-groove (hook section).	I, II	From 1 in 120 at breech to 1 in 30 at 43·77 ins. from the muzzle; remainder uniform 1 in 30	87·77	Pad	16 24 §	Axial	1900	626	5·4	4-inch ...	**II, IIP, III IIIA, IV V, VI
,,		From 1 in 120 at breech to 1 in 30 at muzzle	82·0	,,	20	Rad'l Steel	—	—	—	4 ,, (jointed)	I
,,	I	From 1 in 120 at breech to 1 in 30 at 44·3 ins. from the muzzle; remainder uniform 1 in 30	88·3	,,	24	Axial	1650	—	—	30-pr.	I
,,	—	From 1 in 120 at breech to 1 in 25 at 40·9 ins. from the muzzle; remainder uniform 1 in 25	81·8	,,	21	Rad'l Steel	1667	385	—	20-pr.	I
	I, II	From 1 in 120 at breech to 1 in 28 at 35·8 ins from the muzzle; remainder uniform 1 in 28	71·6	,,	12 18 §	,, ,,	1720	249	—	12-pr., 7 cwt.	I
,,	—	From 1 in 37 at breech to 1 in 28 at muzzle	49·25	,,	18	,,	—	—	—	12-pr., 6 cwt.	I
—	—	Smooth bore......	—	Cup	—	Rad'l Cop'r	—	—	—	32-pr. S.B.B.L.	I
										Howitzers.	
Poly-groove (hook section)	I	–	—	—	—	Axial	—	—	—	6-in., 30 cwt.	I
,,	I	Uniform 1 in 15	59·425	Pad	24	,,	—	—	—	6-in., 25 ,,	I
,,	I	Uniform 1 in 28	48·4	,,	21	,,	—	—	—	5·4-in.	I
,,	I	Uniform 1 in 28	36·8	,,	20	,,	—	—	—	5-in.	I

The addition P to a Mark indicates that the gun has been converted from the system of friction to that of percussion firing.

All 4-inch and 12-pr. B.L. guns, o later manufacture, and existing guns when "through-lined," or repaired with a new A tube, will be rifled with six grooves per inch of calibre.

BREECH-LOADING

	Mark.	Material.	Service.	Total Length.	Bore.		Chamber.		
					Calibre.	Length in Calibres.	Diameter.	Length to base of Projectile.	Capacity.
				Ins.	Ins.		Ins.	Ins.	Cubic Ins.
7-inch 82 cwt. ...	—	Wrought-iron	C	120·0	7·0	14·21	7·20	16·0	620·0
,, 72 ,, ...	—	,, ...	L	118·0	7·0	14·21 or 13·93	7·20	14·25	552·9
40-pr. 35 cwt. ...	—	Wrought-iron and Steel ..	C	121·0	4·75	22·39	4·96	13·5	257·8
40 ,, 32 ,, ...	—	,, ,, ..	C	120·0					
20 ,, 16 ,, ...	—	,, ,, ...	L	96·0	3·75	22·36	3·94	12·0	143·0
20 ,, 15 ,, ... 20 ,, 13 ,, ...	—	,, ,, ..	N	66·125	3·75	14·43	3·94	11·0	131·0
12-pr. 8 cwt. ...	—	Wrought-iron and Steel .	C	72·0	3·0	20·458	3·20	8·5	66·0
9 ,, 6 ,. ...	—	Wrought-iron	C	62·0	3·0	17·5	3·20	7·0	55·1

BREECH-LOADING

ORDNANCE.		FUZES.				Tubes.	CHARGES—Weight in lbs.
		Time.		Percussion.			
Nature.	Mark.	Land Service.	Naval Service.	Land Service.	Naval Service		Full.
16·25-inch	—	—	One middle time & percussion to e'ch shrapn'l shell, 20 % spare A; Middle Sensitive B	—	Direct action (C)	P	960 S.B.Ca. Mark II.
13·5 ,,	I II, IIA	—	,,	—	,,	,,	630c S.B.C.
13·5 ,,	III IIIA, B, C, D, E, F IV	Middle Sensitive	,,	Direct action (C)	,,	,,	
12 ,, ...	I, IA	,,	—	,,	—	,,	·95c Prism¹ Brown, Mk IIIE, Mark IIE.
12 ,, ...	III, IV, V VW	—	,,	—	,,	,,	

For footnotes to Breech-loading

ORDNANCE (R.B.L.).

RIFLING.			VENT.	BALLISTIC EFFECTS WITH FULL CHARGES.				
						Penetration of Wrought-Iron Armour Plate.		
System.	Twist in Calibres.	Length.	Position	Muzzle Velocity.	Muzzle Energy.	At 1000 Yards.	At 2000 Yards.	
		Ins.		f.s.	Ft.-tons	Ins.	Ins.	
Polygroove ...	U. 1 in 37 cals. ...	83·1	[a]Through vent-piece, striking cartridge at centre of base.	1100[b]	847	5	4	7-in., 82 cwt.
,, ...	,, ,, ...	82·9		1100[b]	847	5	4	,, 72 ,,
Polygroove ...	U. 1 in 36¼ cals. ...	92·5		1160	374	—	—	40-pr., 35 cwt. ,, 32 ,,
...	U. 1 in 38 ,, ...	71·6		1130	194	—	—	20-pr., 16 ,,
	,, ,, ,, ...	42·75		1000	156	—	—	,, 15 ,, ,, 13 ,,
Polygroove ...	U. 1 in 38 cals. ...	52·5		1239	119	—	—	12-pr., 8 cwt.
,, ...	,, ,, ...	45·5		1055	66	—	—	9-pr., 6 ,,

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[a] 40-pr. side-closing has a copper radial vent 6·5 inches from end of bore inclined at angle of 45° to vertical plane of axis of gun on right side.

[b] Difference in size of chamber gives same M.V. in these two guns although fired with different charges.

ORDNANCE (B.L.).

CHARGES—Weight in lbs.		PROJECTILES.																ORDNANCE.	
		Common Shell.					Shrapnel Shell.					Shot.							
Reduced for Naval Service.	Saluting, Blank L.G.	Mark.	Weight of Shell, Empty, Plugged.		Weight of Bursting Charge, P. & F.G.		Mark.	Weight of Shell, Empty, Plugged.		Weight of Bursting Charge.		Mark.	Palliser.	Mark.	Armour Piercing Forged Steel.	Mark.	Case, Land Service Only.	Nature.	Mark.
			lb.	oz.	lb.	oz.		lb.	oz.	lb.	oz.		lb.		lb.		lb.		
720[b] & 480[c] S.B.C.	—	IIo IIIp	1607 1619	0 13	187 179	8 4	Io	1792	0	8	0	I	1800	I	1800	—	—	16·25-in. ...	—
472½[d] and 315[e] S.B.C.	45	IIp	1164	1	85	9	Ip	1243	15	5	4	I	1250	I	1250	—	—	13·5 ,,	I II, IIA
																		13·5 ,,	III IIIA, B, C, D, E, F IV
221½[d] Prism[1] Brown	35	II	681	11	21	9	II	711	5	1	14	II	714	I	714	I	714	12 ,, ...	I, IA
		IIIo	618	8	95	0	IIIo	710	14	2	0							12 ,,	III, IV, V Vw

Ordnance (B.L.) see pages 330 and 331.

ORDNANCE.		FUZES.				Tubes.	CHARGES—Weight in lbs.
		Time.		Percussion.			
Nature.	Mark.	Land Service.	Naval Service.	Land Service.	Naval Service		Full.
12-inch ...	VI, VII	Middle Sensitive	—	Direct action C	—	P	295c Prism^{l} Brown, M'k IIIw, Mark IIz.
12 ,, wire	VIII	—	One Middle Time & Percussion to each Shrapn'l Shell, 20 spare (A); Middle Sensitive (B)	—	Direct action (C)	,,	Corditeq
10 ,, ...	I	,,	—	,,	—	,,	252c Prism^{l} Brown
10 ,, ...	II, III, IV	,,	,,	,,	,,	,,	
10 ,, ...	IIIA	—	,,	—	,,	,,	
9·2 ,, ...	I, cI, & u.cI	,,	,,	,,	,,	,,	140c Prism^{l} Brown
9·2 ,, ...	II	—	,,	—	,,	,,	
9·2 ,, ...	III, V, VII.	—	,,	—	,,	,,	164c Prism^{l} Brown
9·2 ,, ...	IV, IVA, VIB	,,	—	,,	—	,,	
9·2 ,, ...	VI, VIA, & VIC	,,	,,	,,	,,	,,	
8 ,, ...	III	—	,,	—	,,	,,	100c Prism^{l} Black 104c Prism^{l} Brown
8 ,, ...	IV	—	,,	—	,,	,,	118c Prism^{l} Brown
8 ,, ...	VI	—	,,	—	,,	,,	
8 ,, ...	VII	T & P middle & middle sensitive	—	,,	—	,,	90c Prism^{l} Black
8 ,, ...	VIIA						
80-pr. ...	I	—	,,	—	,,	,,	34 S.P., M'rk, III
6-inch ...	III	—	,,	—	,,	,,	48cq, 36d E.X.E. 14½. Cordite. Size 20/14f.
6 ,, ...	IV, VI	,,	,,	,,	,,	,,	48c E.X.E., 45c Prism^{l} Black. 14½. Cordite. Size 20/14.
6 ,, ...	V	,,	—	,,	—	,,	45c Prism^{l} Black. 14½. Cordite. Size 20/14.

For footnotes to Breech-loading

ORDNANCE (*B.L.*).—(*Continued*).

Charges—Weight in lbs.		**Projectiles.**												**Ordnance.**	
		Common Shell.			Shrapnel Shell.			Shot.							
Reduced for Naval Service.	Saluting, Blank L.G.	Mark.	Weight of Shell Empty, Plugged. lb. oz.	Weight of Bursting Charge, P. & F.G. lb. oz.	Mark.	Weight of Shell Empty, Plugged. lb. oz.	Weight of Bursting Charge. lb. oz.	Mark.	Palliser. lb.	Mark.	Armour Piercing Forged Steel. lb.	Mark.	Case, Land Service Only. lb.	Nature.	Mark.
147½e Prism¹ Brown	35	V*p*	634 1	79 0	IV*p*	709 11	3 0	II	714	I	714	I	714	12-inch ...	VI, VII
—	—	I*p*	769 2⅝	80 13½	I*p*	846 8	3 8	—	850	I	850	—	—	12 ,, wire	VIII
189*d* & 126*e* Prism¹ Brown	25	I*p*	461 5	37 12	I*p*	497 10	1 9	I	500	I	500	I	500	10 ,, ...	I
														10 ,, ...	II, III, IV
												—	—	10 ,, ...	IIIA
105*d* & 70*e* Prism¹ Brown, 65 P² *nz*	20	II	361 1	18 8	II	377 13	1 6	IV	380	I	380	I	380	9·2 ,, ...	I, cI, U.C I
												—	—	9·2 ,, ...	II
		III*o*	346 8	33 0	III*o*	377 6	1 8					—	—	9·2 ,, ...	III, V, VII
123*d* & 82*e* Prism¹ Brown	20	V*p*	348 11	31 14	IV*p*	377 0	2 3					I	380	9·2 ,, ...	IV, IVA, VI
														9·2 ,, ...	VI, VIA. VIc
75*d* & 50*e* Prism¹ Black, 45 P² *nz*	15	II	195 7	13 8	III	208 3½	0 15½	II	210	I	210	—	—	8 ,, ...	III
88½*d* & 59*e* Prism¹ Brown, 45 P² *nz*	15	III*o*	180 8	29 0	IV*o*	207 12	1 2							8 ,, ...	IV
		IV*p*	190 9	18 8	V*p*	208 4	0 15							8 ,, ...	VI
67½*dx* Prism¹ Black	15	II*p*	163 3¾	15 13½	II*p*	177 12	0 15	II	180	—	*v*	I	160	8 ,, ...	VII
														8 ,, ...	VIIA
25 S.P.	7	II III*l* III*p*	74 8½ 81 10 71 13½	6 2 7 12 7 3½	II*o*	79 0	0 3	II	$78\frac{7}{16}$	—	—	—	—	80-pr. ...	I
36*d* & 24*e* E.X.E., 24½ P² *nz*	—	—	—	—	—	—	—	—	—	—	—	—	—	6-inch ...	III
36*d* & 24*e* E.X.E., 22½ Prism¹ Black, 24½ P² *nz*	7	III V VI*p*	91 13 — 90 3	7 6 9 1 9 13	II — IV*o*	98 12 — 98 8	0 7 — 0 10½	IV	100	I	100	I	100	6 ,, ...	IV, VI
—	—	—	—	—	V*p*	98 8	0 10½	IV	100	I	100	I	100	6 ,, ...	V

Ordnance (B.L., **see pages 330 and 331.**

BREECH-LOADING

ORDNANCE.		FUZES.					CHARGES.
		Time.		Percussion.			
Nature.	Mark.	Land Service.	Naval Service.	Land Service.	Naval Service	Tubes.	Full.
5-inch	II	-	One Middle Time & Percussion to each Shrapn'l Shell, 20 spare A. Middle Sensitive (B)	—	Direct action C	P	15¾lb. S.P.[c] 4lb. 7¼oz. Cordite.
5 ,, ...	III, IV, V	Middle Sensitive & T. & P. Middle	,,	Direct action (C)	,,	,,	
4 ,, ...	II, IIP, III, IIIA, IV	—	,,	—	,,	,,	12lb. S.P. 3lb. 1oz. Cordite, Size 5/11
4 ,, ...	V, VI	T. & P. Short A T. & P. Mk. IV B	,,	Small percussion	,,	P[h]	
4 ,, jointed	—	T. & P. Short A T. & P. Mk. IV B Middle Sensitive[j]	—	,,	,,	Short or solid drawn	—
30-pr.	I	—	—	,	—	—	2lb. 6oz. Cordite, Size 5/11.
20-pr.	I	T. & P. Short A T. & P. Mk. IV. (B)	-	,,	—	,,	6lb. S.P.
12-pr., 7 cwt....	I	,,	—	,,	—	,,	4lb. S.P.
15-pr., ,, ...	I	T. & P. Mk. IV.	—	—	—	T	15¾oz. Cordite, Size 5.11.
12-pr., 6 cwt.	I	,,	—	—	—	,,	12$\frac{7}{16}$oz. Cordite, Size 5.11.
32-pr. S.B.B.L.	I	—	—	—	—	Short or solid drawn	3lb. R.L.G.[g]
HOWITZERS.							
6-inch, 30 cwt.	—	Sensitive Middle	—	Direct action (C), and D.A. Delay	—	P	—
6 ,, 25 ,,	I	,,	—	,,	—	,,	—
5·4 ,, ...	I	—	—	—	—	T	—
5 ,, ...	I	T. & P. Mk. IV	—	D.A. or D.A. Delay	—	,,	—

[a] In 8 cartridges.
[b] In 6 cartridges.
[c] In 4 cartridges.
[d] In 3 cartridges.
[e] In 2 cartridges.
[f] For Mark III chasehooped, and Mark IV. guns and upwards.

[g] This charge of E.X.E. is not to be used with unchasehooped guns, and only with chasehooped guns when on "Vavasseur Broadside" and "Vavasseur Central Pivot" carriages.

[h] Some Mark II. guns still fire M tubes.
[l] Double shell.
[m] Star shell also used.
[n] Practice only.
[o] Forged steel.
[p] Cast-steel.

ORDNANCE (*B.L.*).—(*Continued*):

Charges.		**Projectiles.**												**Ordnance.**	
		Common Shell.			Shrapnel Shell.			Shot.							
Reduced.	Saluting, Blank L.G.	Mark.	Weight of Shell Empty.	Weight of Bursting Charge, P. & F.G.	Mark.	Weight of Shell Empty.	Weight of Bursting Charge.	Mark.	Palliser.	Mark.	Armour Piercing Forged Steel.	Mark.	Case, Land Service Only.	Nature.	Mark.
			lb. oz.	lb. oz.		lb. oz.	lb. oz.		lb.				lb.		
7¾lb. S.P.*w* $8\frac{6}{16}$ P^2*nw*	8	III IV V*o*	46 5¼ 41 13¾	4 1 6 15	III*o*	49 9	0 4½	I II	50	I	50	I	50	5-inch ... 5 ,, ...	II III, IV, V
—	4	III IV V VI	21 12 — 21 7	1 6 2 9½ 2 14½	III — IV*o* V*o*	24 0 — 24 1½	0 3 — 0 1½	I — II	25	—	—	I	25	4 ,, 4 ,, ...	II, IIr, III IIIA, IV V, VI
—	—	—	—	—	—	—	—	I	—	—	—	—	—	4 ,, (j'nted)	—
—	—	—	—	—	—	—	—	—	—	—	—	I	30	30-pr. ...	I
—	—	*m*	17 4	1 5	—	19 1	0 1	—	—	—	—	—	20	20-pr. ...	I
—	1½ Mk. II	I*o* I*n*	10 10 11 8½	1 8½ 0 10	I*o* I*ny*	11 10½ 11 10½	0 0¾ 0 0¾	—	—	—	—	II	$12\frac{15}{16}$	12-pr., 7 cwt.	I
—	—	—	—	—	I	14 11½	0 1½	—	—	—	—	I	$12\frac{15}{16}$	15-pr., ,,	I
—	—	—	—	—	I	12 6½	0 1½	—	—	—	—	I	$12\frac{15}{16}$	12-pr., 6 cwt.	I
—	—	—	—	—	—	—	—	—	—	—	—	IV	54½	32-pr. S.B.B.L	I
														Howitzers.	
—	—	I*p* I*o*	103 8 103 2	14 7 14 13	I	98 8	0 10½	—	—	—	—	I	100	6-inch, 30 cwt.	—
—	—	I*p* I*o*	103 8 103 2	14 7 14 13	— I*r*	98 8 111 1	0 10½ 6 9½	—	—	—	—	I	100	6 ,, 25 ,,	I
—	—	—	—	—	—	—	—	—	—	—	—	—	—	5·4 ,, ...	—
—	—	I*o*	45 3	4 4	I*o*	48 15	C 4	—	—	—	—	I	50	5 ,, ...	—

---

q Charge not yet finally settled.
r Ring shell.
v A segment shell weighing 180lbs. is also used.
w For Naval Service.
x For Land Service.
y The existing stock of these shells will be used up over *sea* ranges, but no more will be made.
z For gunnery ships.
A For present use.
B For future use.
C For L.S. Mark I.* or II. are to be used on land fronts, Mark III. sea fronts. For N.S., Mark III. only is to be used.

ORDNANCE. — Nature and Weight.	Mark.	FUZES.					CHARGES.	
		Time.		Percussion.		Tubes.	Silk Cloth Cartridges.	
		L.S.	S.S.	L.S.	S.S.		Full.	Saluting Blank. R.L.G. or L.G.
							lb.	lb. oz.
7-in. 82 cwt. ...	—	15secs. with det. III, mid. sensitive*b*	15secs. with det. III, mid. sensitive*b*	Direct Action	—	Short or solid drawn with primer	11 R.L.G.²c	7 0
„ 72 „ ...	—	„	—	„	—	„	10 „ c	7 0
40-pr. 35 cwt. „ 32 „	—	15secs. with det. III, mid. sensitive*b*	15secs. with det. III, mid. sensitive*b*	R.L.	R.L. perc. and Dir. Act.		5 R.L.G.²	3 0
20-pr. 16 „ ...	—	E. time	—	B.L. plain	—	Short or solid drawn	2½ „	1 5
„ 15 „ „ 13 „	—	—	E. time	„	R.L. and Dir. Act. for Com. B.L. plain for segment	„	2½ „	1 9
12-pr. 8 cwt. ...	—	15secs. with det. III. short T & *Pb*, E time for segment	E. time	B.L. plain	B.L. plain	Short or solid drawn	1½ R.L.G.²	1 0
9 „ 6 „ ...	—	„	„	„	„	„	1¼ „	1 0

---

b For future use.

c Owing to difference in size of chamber in these two guns, the same M.V. is obtained from both.

ORDNANCE (R.B.L.).

Projectiles.																					
With Lead Coating.																	Solid Shot.		Case Shot.			
Empty.									Bursting Charges.												
Common Shell.		Segment Shell.		Shrapnel Shell.		Common Shell. P.&F.G.		Common Shell. L.G.		Segment Shell.			Shrapnel Shell.							
Mk.	lb. oz.	Mk.	lb. oz.	Mk.	lb. oz.	lb. oz.		lb. oz.		lb. oz. gr.			lb. oz.		lb. oz.		Mk.	lb. oz.		
II ...	83 0 98 0	I	98 9 11/16	II*d*	97 0	8 4 10 5		6 1½ 8 8		3 2 0			0 8		—		VI	68 2½		7-in. 82 cwt.
—	98 0	I	98 9 11/16	II*d*	97 0	10 5		8 8		3 2 0			0 8		—		VI	68 2½		,, 72 ,,
II	8 85	I	88 9½	I	89 0	2 6		2 0		0 13 0			0 3		40 1½		II	31 8		40-pr. 35 cwt. ,, 32 ,,
II	20 8	II	19 10	—	—	—		1 2		700 grs. Shell F.G.			—		20 9¼		IV	20 5½		20-pr. 16 ,,
III	20 8	I	19 10	—	-	1 5		1 2		700 ,,			—		20 9¼		—	—		,, 15 ,, ,, 13 ,,
III	10 12	I	10 8	II	10 12	—		0 8		550 grs.			0 0¾		11 7		IV	11 8		12-pr. 8 cwt.
III	8 3	I	8 5	II	8 12	—		0 6		800 ,,			0 0¼		8 13		III	9 0		9 ,, 6 ,,

d None now issued.

B.L. CARRIAGES AND SLIDES (LAND SERVICE).

Ordnance.	Carriages.		Elevation in Degrees.	Depression in Degrees.	Slides.		Radii of Racers.				Height of axis of trunnions above the ground, in firing position.		Weight.			
	Material.	Nature.			Material.	Nature.	Front.		Rear.				Carriage.		Slide.	
							ft.	in.	ft.	in.	ft.	ins.	ts.	ct.	ts.	ct.
13·5-in., 67 tons	Steel	Disappearing, Mk. I.	15	7	Steel	—	8	0	8	0	19	0	—		—	
12-in. 47 ,,	,,	Upper or lower tier.	7	4	,,	Lower tier ...	9	2	21	2	5	1½	8	2¾	14	4¾
48 ,,					,,	Upper tier ...	9	2	18	0					13	19½
10-in. 32 ,,	,,	Disappearing, Mk. I.	15	5	—	—	6	0	6	0	11	8¼	60	11	—	
	,,	Do. Mk. II ..	15	5†	—	—	14	6	14	6	14	6	—		—	
	,,	Do. Mk. III. ..	16	7	—	—	¶9 **10	9½ 2¼	9 10	9½ 2¼	13	6	53	12	—	
29 ,,	,,	Barbette, Mk. I.	15	6½	Steel	Barbette, Mk. I. C pivot.	5	11·13	5	11·13	9	8	11	8¼	9	13¾
					,,	Do. do. D pivot	9	6	3	8¼	9	8	11	4	10	11¼
	,,	Do. Mk. II ..	17	5	,,	Do. Mk. II ...	10	10	10	10	9	8¼	11	3	45	11
	,,	Do. Mk. III .	15	5	,,	Do. Mk. III ...	10	10	10	10	9	6	7	3¼	41	16¼
9·2 in. 22 ,,	,,	Disappearing, Mk. I.	15	5	—	—	5	6	5	6	11	0	50	5¼	—	
	,,	Do. Mk. II ...	15	5	—	—	13	6	13	6	14	6	43	18	—	
23 ,,	,,	Barbette, Mks. I and IA.	15	6½	Steel	Barbette, Mks. I and IA	5	11·13	5	11·13	9	8	11	4	10	9¼
	,,	Do. Mk. II ...	17	5	,,	Do. Mk. II ...	10	10	10	10	9	8¼	11	3	45	11
8-in., 12 ,, ...	Iron	Do. Mk. I ...	12½	5	Iron	Do. Elswick ...	5	6	5	6	7	7¾	4	11¾	3	17¼
6-in., 5 ,,	Steel	‡Disappearing, Mk. I.	15	5	—	—	5	0	5	0	10	8	15	5	—	
	,,	§Do. Mks. II & II*.	20	5	—	—	4	4	4	4	10	8	14	5¼	—	
	,,	‡Do. Mk. III .	20	5	—	—	4	4	4	4	10	8	14	16¼	—	
	,,	§Do. Mk. IV ..	20	5	—	—	4	4	4	4	10	8	13	3	—	
	,,	Barbette, Mk. I	15	7	Steel	Barbette, Mk. I	3	9	3	9	7	9¼	2	12	2	10
	,,	Do. V.C.P. Mk. I	15	15	,,	Do. V.C.P., Mk. I.	2	3¼	2	3¼	3	6¼	—		—	
5-in., 40cwt.	,,	Travelling, 6ft. parapet.	25	5	—	—	—		—		6	6	1	15	—	
	,,	Disappearing	—	—	—	—	—		—		—		—		—	
4-in., 26 ,, ...	,,	Travelling, 6ft. parapet.	25	5	—	—	—		—		6	6	1	9	—	
4-in., 25cwt., jointed gun)	,,	Travelling ...	17	8	—	—	—		—		3	7½	0	18	—	
30-pr., 20cwt. ...	,,	Field, hydraulic	—	—	—	—	—		—		—		—		—	
20-pr., 12 ,,	,,	Field, Mk. I ...	16	5	—	—	—		—		3	6	—		—	
15 pr. 7 ,, ‖	,,	Do. Mk. II ..	16	5	—	—	—		—		3	4	0	11½	0	10¾††
	,,	Do. Mk. II* ..	16	5	—	—	—		—		3	4	0	11	0	10¾††
12-pr., 7 ,, ...	,,	Do. Mk. I ...	16	8	—	—	—		—		3	3½	0	11¼	0	10¾††
12-pr., 6 ,,	,,	Do. Do.	16	8	—	—	—		—		3	4	—		—	
32-pr., S.B. B.L., 42cwt.	Iron	Sliding, Medium No. 6.	10	15	Iron	Traversing Medium, No. 6	1	6	6	10	3	7	0	14¼	0	13
HOWITZERS.																
6-in., 20cwt. ..	Steel	Siege, Mk. I ...	35‡‡	—	—	—	—		—		4	5½§§	—		—	
6-in., 25 ,, ...	,,	Do. Mk. I ...	35‡‡	—	—	—	—		—		4	5½	2	5¼	—	
5·4-in., 12¾cwt....	,,	Field, Mk. I ...	45	5	—	—	—		—		3	9	—		—	
5-in., 9cwt. ...	,,	Do. Mk. I ..	45	5	—	—	—		—		3	7	—		—	

† But can go to 7½ degrees if emplacement admits.
‡ For Mark V gun.
§ For Marks IV and VI guns.
‖ For India.
¶ Inner.
** Outer.
†† Weight of limber, without stores.
‡‡ When used with top carriage as howitzer bed 70 can be obtained.
§§ When used as a howitzer bed 4ft. 10ins.

See Note "†," page 324, Mark II, II*, 12-pr., B.L., carriages will be utilized for 15-pr. equipment, and when converted will be designated "carriages, field, B.L., 15-pr., Mark I."

R.B.L. CARRIAGES AND SLIDES.

Ordnance.	Carriages.		Elevation in Degrees.	Depression in Degrees.	Slides (Traversing, Medium).		Radii of Racers.		Height of Axis of trunnions above the ground in firing position.	Weight.	
	Material.	Nature.			Material.	Nature.	Front.	Rear.		Carriage.	Slide.
							ft. in.	ft. in.	ft. in.	ts. ct.	ts. ct.
7-in., 82cwt.	Iron	Moncrieff with platform.	15	5	—	—	† 6 10 ‡ 8 11	6 10 4 8½	10 5¾	13 2¾	
	,,	Sliding, Medium, No. 1.	13½	8½	Iron	No. 1, 4ft. 3in. parapet converted	5 0	14 0	5 5½	—	2 10
					,,	No. 2, 3ft 6in....	5 0	14 0	4 8½	1 11½	2 10
					,,	No. 3, 2ft. 7in....	5 0	14 0	3 9½	—	2 10
	,,	Do. do., No. 2 ...	13½	8½	Wood	No. 11, 4ft. 3in. parapet.	† 6 1 ‡ 9 0 § 10 8½ ‖ 12 10	6 1 3 4½ 2 2 2 2	5 2¾	1 3¾	2 4
					,,	No. 12, 3ft. 6in. parapet.	5 0	16 6	4 7½	—	1 14¾
	,,	Do. do., No. 3 ...	13½	8½	,,	No. 13, 3ft. 6in parapet 11′ long	5 0	14 0	4 8½	1 11½	1 10¾
	Wood	Do. do., No. 15	*8	6	,,	No. 14, casemate	5 0	16 6	3 7½	0 15	1 7
	,,	Do. do., No. 16	*22	6	,,	No. 16, dwarf	† 6 1 ‡ 9 8 § 10 8½ ‖ 12 10	6 1 3 4½ 2 2 2 2	5 2½	0 15½	
7-in., 72cwt.	,,	Do. do., No. 17	*19	6					— 5 2	— 0 15	1 17
	,,	Do. do., No. 18	*8½	6	,,	No. 15, converted	—	—	3 7½	0 14½	0 18¾
40-pr., 35 and 32cwt.	Iron	Common standing.	24	9	—	—	—	—	3 5	0 17½	
	,,	Siege, 6-ft. parapet, side closing	15	5	—	—	—	—	6 5½	1 6¾	¶ 13½
	Wood	Siege	11	8½	—	—	—	—	4 4	1 8	¶ 12
	Iron	Sliding, Medium, No 4.	8	15	Iron	No. 4	1 7½	8 7½	3 11	1 1	1 2
	Wood	Do. do., No. 19	*17½	6	Wood	No. 14, casemate	5 0	16 6	3 8½	0 10½	1 7
	,,	Do. do., No. 20	*20	5	,,	No. 17, dwarf ...	5 0	16 6	4 10½	0 11½	1 12¾
20-pr., 16cwt.	Iron	Do. do., No. 5 ...	10	15	Iron	No. 5	1 5	6 10	3 8½		
	Wood	Field	—	—	—	—	—	—	—	0 16	¶ 10¾
12-pr., 8 ,, ...	,,	Field									¶
9-pr., 6 ,, ...	,,	Field									

* Elevation from bed, with screw removed.
† C pivot.
‡ D pivot.
§ E pivot.
‖ F pivot.
¶ Weight of limber without stores.

B.L. GUN MOUNTINGS (NAVAL).

Carriages.	Weight.	Freight Measurement.	Width.	Length of		Elevation.	Depression.	Height of Axis of Trunnions.	
				Carriage.	Gun and Carriage.			From top of Slide.	From deck with guns run out.
	ct. qr. lb.	tons.	ft ins.	ft. ins.	ft. ins.	deg.	deg.	ins.	ins.
10-inch V.C.P. I‡...	72 0 0	—	6 8·3	5 1·3	33 9·6	14	5	19·5	63·5
9·2 ,, V.B. Mark I	55 1 0	4·6	6 0	4 9	21 8	10	5	16½	51·0
9·2 ,, V.C.P. Mark I	38 0 0	—	6 2	5 0	25 10	15	5	21	†52·0
9·2 ,, V.C.P. Mark II	49 3 0	—	6 0	4 8	25 10	12	5	17	†48·0
9·2 ,, V.C.P. Mark III	44 0 0	—	—	—	—	15	5	—	†39
8 ,, V.B. Mark I	45 2 0	2·7	5 10	6 5½	18 6½	10	4½	16¾	39·5
8 ,, V.C.P., Mark I	35 0 0	—	5 2	7 8	21 6	15	5	15	52·5
6 ,, A.B. Mark I	23 1 0	0·955	4 3	4 7½	13 9½	13	8	23½	34·5
6 ,, V.B. Mark I	23 1 0	1·33	4 4½	5 7½	13 9½	16	6	11½	40·0
6 ,, V.B. Mark II...	23 2 0	1·141	5 0	3 6	13 9½	16	7	13¾	40·0
6 ,, V.C.P. Mark I	22 1 0	1 557	4 2	3 7	13 9½	20	7	13½	44 9
6 ,, V.C.P. Mark II	17 2 0	—	—	—	—	15	7	—	42·25
5 ,, V.B. Mark I	11 2 0	0·895	3 1	3 6½	11 7½	15	7½	9	37·15
5 ,, V.B. Mark II...	11 2 0	0·895	2 11	3 6½	11 7½	22	7½	9	37·15
5 ,, V.C.P. Mark I	12 0 0	0·86	3 1	3 6½	11 7½	20	7½	9	38·5
4 ,, V.B. Mark I	6 0 0	0·842	2 8½	2 4½	10 0	18½	28	7½	29·75
4 ,, V.B. Mark II...	7 0 0	0·49	3 0	3 1	10 0	20	30	7½	30·75
4 ,, V.C.P. Mark I	8 2 0	—	2 9½	2 10	10 0	20	20	7½	30·75

† From platform.
§ Without shield.
‡ As mounted in "Sans Pareil."

SLIDES.

Slides.	Weight.	Freight Measurement.	Length.	Width.	Height.		Incline.
					Front.	Rear.	
	cwt. qrs. lbs.		ft. ins.	ft. ins.	ft. ins.	ft. ins.	degrees.
10-inch V.C.P. I ("Sans Pareil").	158 2 0	—	11 3·2 overall*	†	2 6 ‡	5 1·5 §	10
9·2-inch V.B. I.	107 1 0	8·5	10′ 6″ or 13′ 6″ including loading platform.	6 9	2 7	3 9	7½
9·2 ,, V.C.P. Mark I	172 0 0 including loading platform	—	8′ 0″ or 12′ 9″ including loading platform.	‖12 8	2 5	3 6½	10
9·2 ,, V.C.P. Mark II ...	227 2 0	—	10′ 4″ or 17′ 3″ including loading platform.	‖9 3	3 0	4 3½	10
8 ,, V.B. Mark I... ...	74 0 0	3·7	10 6	7 3	1 5½	2 5½	6
8 ,, V.C.P.	74 1 7	—	8 6	5 0	3 3	4 9	12
6 ,, A.B. Mark I... ...	34 1 0	2·905	10 4	5 1½	0 10½	1 3	3
6 ,, V.B. Mark I ...	37 3 0	3·452	9 0	5 6	2 0	2 11½	7½
6 ,, V.B. Mark II ...	41 3 0	—	8 0	4 8	2 0	3 2	12
6 ,, V.C.P.	45 3 0	2·81	7 8	‖6 9	2 4	3 3	10
6 ,, V.C.P. Mark II ...	—	—	—	—	—	—	—
5 ,, V.B. Mark I... ...	27 3 0	2·655	6 4	4 11	2 2½	3 0½	15
5 ,, V.B. Mark II ...	26 0 0	—	5 7½	3 6	2 2	3 2¼	15
5 ,, V.C.P.	19 2 0	1·484	5 3½	3 8	2 4	3 3½	15
4 ,, V.B. Mark I... ...	11 1 17	0·745	3 7	2 6½	1 8½	2 5	15
4 ,, V.B. Mark II ...	21 2 0	1·408	6 2	3 10	1 9½	2 6	15
4 ,, V.C.P.	13 2 0	—	4 5	3 1	1 10	2 8	15

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* Length of sliding surface=6′ 10″·5. From front of slide to rear face of revolving gun house=17′ 10″·7.

† 7′ 4″ across roller brackets. 5′ 9″ across faces of slide.

‡ From top of slide to bottom of roller bracket.

§ From top of piston rod bracket to bottom of roller bracket. Height of rear end of slide face above bottom of slide girder=3′ 2″·58. Height of front end of slide face=2′ 0″·26.

‖ Width over training handles.

SLIDES.

Pivot Bar.				Buffers.			Remarks.
Distance between centres of Holes.	Diameter of Holes.		Distance between centres of Pivots.	Recoil allowed.	Internal Diameter of Cylinders.	Working Quantity of Liquid.	
	Front.	Rear.					
ft. ins.	ins.	ins.	ft. ins.	ft. ins.	ins.	Quarts.	
No	Pivot	Bar.		0 33	9·001	—	
3 9	4	2 of 3	12 11	3 6	—	—	
—	—	—	—	2 6	8·0	—	Weight of pivot plate, 39cwt.
—	—	—	—	3 0	—	—	
4 8	—	2 of 3½	—	3 0	7·45	64	
—	—	—	—	2 6	6·0	27½	Weight of pivot plate, 38cwt. ·2qrs.
2 0	—	2 of 2¼	10 7·8	4 0	—	—	
3 0			10 10·5				
3 6	3	2 of 4¼	10 4·5	3 6	5·1	21¾	
3 9			11 4·5				
Slid	ing Pi	vot.	8 4¾	2 0	5·1	—	
—	—	—	—	2 0	5·1	17	Weight of pivot plate, 20cwt.
—	—	—	—	—	—	—	
Slid	ing Pi	vot.	7 5	1 8	5·1	12¼	
Slid	ing Pi	vot.	7 0	1 8	5·1	12¼	
—	—	—	—	1 8	5·1	12¼	Weight of pivot plate, 9cwt. 1qr. 7lbs.
—	—	—	—	0 11	5·1	7	
Slid	ing Pi	vot.	6 5	0 11	5·1	7	
—	—	—	—	1 2	5·1	9	Weight of pivot plate, 5cwt. 1qr. 12lbs.

Nature of Gun.	Racers.						
	Clip.				Front.		
	Radius.	Breadth.	Thickness.	Height of Rib.	Radius.	Breadth.	Thickness.
	inches.	inches.	inches.	inches.	inches.	inches.	inches.
4-inch V.B. Mark I. ...	20·5	8·4	1·625	4 6	24·8	8·4	0·75
4 „ V.B. Mark II. ...	Semi-circular pivot plate, radius 19″				—	—	–
4 „ V.C.P.	Diameter of pivot plate, 3′ 10¾″				—	—	–
5 „ V.B. Mark II ...	Semi-circular pivot plate, radius 24·5″				—	—	–
5 „ V.B. Mark I. ...	„	„	„	24·5″	—	—	–
5 „ V.C.P.	Circular pivot plate 56·8 ins. outside diameter.					—	–
6 „ A.B. Mark I. ...	—	—	—	—	36·4	8·5	–
6 „ V.B. Mark I.	36″ bar 41·43 42″ „ 46·99 45″ „ 49·82	10 0	·65	4·0	60·0 65·8 68·6	8 0	1·25
6 „ V.B. Mark II. ...	—	—	—	—	—	—	–
6 „ V.C.P.	—	Circular pivot plate 72·5 ins. outside diameter.					
6 „ V.C.P. Mark II. ...	—	—	—	—	—	—	–
8 „ V.B. Mark I ...	57·5	20 includes front racer	·75	4·375	—	9·2	·65
8 „ V.C.P.	—	Circular pivot plate 92 ins. outside diameter.					
9·2 „ V.B.	59·5	11·0	·75	4·5	75·5	8·0	1·5
9·2 „ V.C.P. Mark I. ...	—	Circular pivot plate 120·95 ins. external diameter.					
9·2 „ V.C.P. Mark II....	—	Circular pivot plate 120 ins. external diameter.					

B.L. MOUNTINGS (NAVAL).

Racers.						Diameter of Pivots.		Remarks.
Rack.			Rear.					
Radius.	Breadth.	Thickness.	Radius.	Breadth.	Thickness.	Front.	Rear.	
inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	
31·0	3·5	2·4	51·5	7·0	7·0	—	—	
44·0	7·0	0·5	66·0	7·0	1·0	1·702	2·0	Clip front racer and rack in one piece, radius 84½ inches.
—	—	—	—	—	—	—	—	
83·24	In one piece with rear racer.		76·5	12·125	1·25	1·702	3 0	
42·5	5·5	·5	76·5	7·5	1·25	1·702	3·0	
—	—	—	—	—	—	—	—	
133·0	7·5	—	121·43	8·5	—	3·0	3·0	
108·81 114·12 117·03	In one piece with rear racer.	·55	117·27 123·2 126 16	17·0	1·25	3·0	3·0	
—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	
96·0	9·0	·5	159·0	9·0	·625	—	—	
—	—	—	—	—	—	—	—	
130·0	6·0	·75	136·0	8·0	1·25	4·0	3·0	
—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	

2.—MUZZLE-LOADING

Ordnance. — Guns.	Mark.	Material.	Service.	Total Length.	Bore.		Chamber.		
					Calibre.	Length in Calibres.	Diameter in Inches.	Length in Inches.	Capacity in Cubic Inches.
				ins.	ins.				
17·72-in., 100 tons ...	I	Wrought-iron, with steel tube	L	391·85	17·72	20·48	19·7	59·72	17049
16-in., 80 tons	I	„ „	C	321·0	16·0	18·0	18·0	59·6	14600
12·5-in., 38 tons ...	I	„ „	C	230·0	12·5	15·84	Unchamb'd	...	...
12·5-in., 38 tons ...	II	„ „	C	222·8	12·5	15·84	14·0	41·125	6000
12-in., 35-ton	I	„ „	C	195·0	12·0	13·54	Unchamb'd	...	...
12-in., 25-ton	II	„ „	C	182·5	12·0	12·09	„	...	...
11-in., 25 tons	II	„ „	C	180·0	11·0	13·18	„	...	...
10·4 in., 28 tons ..	I	„ „	L	289·0	10·4	26·00	12·5	56	6666
10-in., 18 tons	II	„ „	C	180·0	10·0	14·55	Unchamb'd	...	...
10-in., 12 tons* ...	III	„ „	L	145·75	10·0	12·5	„	...	...
9-in., 12 tons	V	„ „	C	156·0	9·0	13·89	„	...	...
9-in., 12 tons	VI A, B, C	„ „	L	145·75	9·0	13·89	„	...	...
8-in., 9 tons	I III	„ „ „ „	L C	144·0	8·0	14·75	„	...	...
7-in., 7-ton	IV	„ „	L	148·0	7·0	18·0	„	...	...
7-in., 6½-ton	III	„ „	C	133·0	7·0	15·86	„	...	...
7-in., 90-cwt.	I	„ „	N	131·0	7·0	15·86	„	...	...
6·6-in., 70 cwt. ..	I	„ „	L	118·0	6·6	14·78	6·8	21·0	70
80-pr., 80 cwt.† ...	—	„ „	L	—	—	—	—	—	—
80-pr. (convd.) 5 tons	I	Cast-iron, W.I. tube	L	136·55	6·29	18·04	Unchamb'd	...	...
64-pr., 64-cwt.	I II	W.I. steel or W.I. tube	L	119·5 120·0	6·3	15·47	„	...	...
64-pr., 64-cwt.	III	W.I., steel tube ...	C	118·0	6·3	15·47	„	...	...
64-pr. (convd.) 71-cwt.	I	Cast-iron, W.I. tube	C	122·72	6·29	16·42	„	...	...
64-pr., convd. 58-cwt.	I	„ „	L	127·45	6·29	17·24	„	...	...
40-pr., 34 cwt.	I	W.I., steel tube ...	L	100·5	4·75	18·0	„	...	...
40-pr., 35 cwt.	II	„ „	L	120·0	4·75	22·0	„	...	...
25-pr., 18 cwt.	I	„ „	L	98·0	4·00	22·0	„	...	...
16-pr., 12 cwt.	I	„ „	L	78·0	3·6	19·0	„	...	...
15-pr. (jointed) 422lb.	I	Steel	L	70·5	3·3	20·0	3·2	3·37	68
13-pr., 8 cwt.	II	W.I. steel tube ...	L	92·0	3·0	28·0	3·15	14·13	110·3

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* This gun is the 9-inch bored up to 10 inches, and is designated 10-inch Mark $\frac{\text{III}}{\text{9-inch I}}$, $\frac{\text{III}}{\text{9-inch II}}$, $\frac{\text{III}}{\text{9-inch III}}$.

† For Victoria, Australia, only.

RDNANCE (R.M.L.)

Rifling.				Vent.	Ballistic Effects with Full Charges.				Ordnance.
							Penetration of Wrought Iron in inches.		
System.	Twist in Calibres.	Length in Inches.	No. of Grooves.	Position. Ins. from end of Bore.	Muzzle Velocity in foot-seconds.	Muzzle Energy in foot-tons.	At 1000 yds.	At 2000 yds.	Guns.
olygroove(plain section)	I. 1 in 150 to 1 in 50, at 2·88 in. from muzzle, remainder U.	302·88	28	Axial	1548	33233	23	21	17·72-in., 100 tons.
,, ...	I. 0 to 1 in 50 cals.	227·4	33	Axial	1540	27950	23	22	1 -in., 80 tons.
Woolwich	I. 0 to 1 in 35 cals.	170·5	9	12·0	1442	11823	16	15	12·5-in., 38 tons, I.
,, ...	I. 1 in 438 to 1 in 35 cals. ...	156·87	9	'Axial	1575	14140	17·5	16	12·5-in., 38 tons, II.
,, ...	I. 0 to 1 in 35 cals....	135·0	9	12·0	1340	8890	14	13	12-in., 35 tons.
,, ...	I. 1 in 100 to 1 in 50 cals ...	127·0	9	9·8	1292	7124	12	11	12-in., 25 tons.
,, ...	I. 0 to 1 in 35 cals....	119·0	9	10·0	1360	7830	13	12	11-in., 25 tons.
olygroove(plain section)	I. 1 in 200 to 1 in 40 cals. ...	213·4	21	Axial	1810	10500	17	15	10·4-in., 28 tons.
Woolwich	I. 1 in 100 to 1 in 40 cals. ...	118·0	7	11·0	1379	5406	12	10	10-in., 18 tons.
olygroove(plain section)	I. 1 in 100 to 1 in 35 cals. ...	101·3	32	2·5	—	—	—	—	10-in., 12 tons, III.
Woolwich	I. 0 to 1 in 45 cals....	104·0	6	9·7	1440	3695	10	9	9-in., 12 tons, I. to V.
olygroove(plain section)	I. 1 in 100 to 1 in 35 at 22·5 in. from muzzle, remainder U.	98·0	27	2·5	1194	—	—	—	9-in., 12 tons, VI. A, B, C.
Woolwich	I. 0 to 1 in 40 cals.... ...	102·0 99·5	4	9·2	1390	2391	8	7	8-in., 9 tons.
,, ...	U. 1 in 35 cals.	110·5	3	8·6	1561	1943	8	6	7-in., 7 tons.
,, ...	U. 1 in 35 cals.	95·535	3	8·6	1525	1854	8	6	7-in., 6½ tons.
,, ...	U. 1 in 35 cals.	95·535	3	8·6	1325	1400	7	6	7-in., 90 cwt.
olygroove(plain section)	I. 1 in 100 to 1 in 35 at 13·2 in. from muzzle, remainder U.	76·5	20	5·2	1416	1398	—	—	6·6 in., 70 cwt.
,, ...	—	—	—	—	1553	1337	—	—	80-pr., 80 cwt.
Woolwich	U. 1 in 40 cals.	106·25	3	1·85	1230	944	—	—	80-pr. (convd.), 5 tons.
Shunt or plain	U. 1 in 40 cals.	90·5	3	5·2 or 6·1 5·2	1125	588	—	—	64-pr., 64 cwt., I., II.
lain	U. 1 in 40 cals.	90·5	3	5·2	1390	897	—	—	64-pr., 64 cwt., III.
,, ...	U. 1 in 40 cals.	96·27	3	1·7	1260	787	—	—	64-pr. (convd.), 71-cwt.
,, ...	U. 1 in 40 cals.	101·45	3	1·8	1260	787	—	—	64-pr. (convd.) 58-cwt.
Woolwich'	U. 1 in 35 cals.	71·5	3	0·6	1340	473	—	—	40-pr., 34 cwt., I.
,, ...	U. 1 in 35 cals.	90·5	3	1·0	1425	555	—	—	40-pr., 35 cwt., II.
,, ...	U. 1 in 35 cals.	78·0	3	1·0	1350	322	—	—	25-pr., 18 cwt.
rench, modified	U. 1 in 30 cals.	58·4	3	0·6	1355	203	—	—	16-pr., 12 cwt.
olygroove(plain section)	I. 1 in 60 to 1 in 20 at 15·13 in. from muzzle, remainder U.	57·13	20	4·8	1040	112	—	—	15-pr., jointed, 422 lb.
,, ...	I. 1 in 100 to 1 in 30 at 9 in. from muzzle, remainder U.	69·0	10	7·0	1595	229	—	—	13-pr., 8 cwt.

‡ 64-pr. Mark I. guns with shunt rifling will be condemned when they come to the Arsenal.

ORDNANCE. Guns.	Mark.	Material.	Service.	Total Length.	Bore.		Chamber.		
					Calibre.	Length in Calibres.	Diameter in Inches.	Length in Inches.	Capacity in Cubic Inches.
				ins.	ins.				
9-pr., 8-cwt.	I	W.I., steel tube ...	L	72·0	3·0	21·17	Unchamb'd	...	...
	II	,, ,,	N						
9-pr., 6-cwt.	I	,, ,,	N	61·0	3·0	16·67	,,	...	...
9-pr., 6-cwt.	II & III	,, ,,	C	74·5	3·0	22·0	,,	...	...
	IV	Steel	N	74·875					
2·5-in. (jointed) 400lb.	I	,, ...	L	70·45	2·5	28·6	2·56	11·07	54
7-pr. (bronze) 200-lb.	II	Bronze	N	38·125	3·0	10·7	Unchamb'd	...	...
7-pr., 200-lb.	IV	Steel	C	41·0	3·0	12·0	,,	...	...
7-pr., 150-lb.	III	,, ...	L	29·125	3·0	8·0	,,	...	...
HOWITZERS.									
8-in., 70-cwt.	I	W.I., steel tube	L	113·0	8·0	12·0	,,	...	...
	II	Steel							
8-in., 46-cwt.	I	W.I., steel tube ...	L	64·0	8·0	6·0	,,	...	...
6·6-in., 36-cwt. ...	I	,, ,,	L	90·7	6·6	12·0	,,	...	...
	II	Steel							
6·3-in., 18-cwt. ...	I	W.I., steel tube ...	L	56·0	6·3	7·14	,,	...	...
4-in. (jointed) 600-lb.	I	Steel	L	57·45	4·0	13·0	,,	...	...

ORDNANCE (*R.M.L.*).—(*Continued*).

Rifling.				**Vent.**	**Ballistic Effects with Full Charges.**				**Ordnance.**
							Penetration of Wrought Iron in inches.		
System.	**Twist in Calibres.**	**Length in Inches.**	**No. of Grooves.**	**Position. Ins. from end of Bore.**	**Muzzle Velocity in foot-seconds.**	**Muzzle Energy in foot-tons.**	**At 1000 yds.**	**At 2000 yds.**	**Guns.**
French, modified	U. 1 in 30 cals.	59·8	3	0·6	1330	119	—	—	9-pr., 8 cwt.
,, ...	U. 1 in 30 cals.	49·3	3	0·6	1250	97	—	—	9-pr., 6 cwt., I.
,, ...	U. 1 in 30 cals.	62·3	3	0·6	1330	121	—	—	9-pr., 6 cwt., II., III., IV.
Polygroove (plain section)	I. 1 in 80 to 1 in 30 at 3·53 in. from muzzle, remainder U.	54·73	8	5·25	1440	100	—	—	2·5-in., 400 lb., jointed
French	U. 1 in 20 cals.	29·5	3	·75	914	40	—	—	7-pr., 200 lb., bronze
,, ...	U. 1 in 20 cals.	34·0	3	1·0	950	47	—	—	7-pr. 200lb., steel.
,, ...	U. 1 in 20 cals.	22·0	3	1·0	673	23	—	—	9-pr., 150 lb.
									Howitzers.
Polygroove (plain section)	I. 1 in 90 to 1 in 35 cals. ...	88·0	24	2·0	956	1150	—	—	8-in., 70 cwt.
Woolwich	U. 1 in 16 cals.	35·5	4	1·75	697	608	—	—	8-in., 46 cwt.
Polygroove (plain section)	I. 1 in 94 to 1 in 35 cals. ...	74·125	20	1·5	839	488	—	—	6·6-in., 36 cwt.
,, ...	I. 1 in 100 to 1 in 35 cals ...	39·7	20	1·125	751	285	—	—	6·3-in., 18 cwt.
,, ...	I. 0 to 1 in 25 at 8·3 in. from muzzle, remainder U.	47·0	13	1·0	835	97	—	—	4-in., jointed, 600 lb.

DING ORDNANCE (R.

ORDNANCE.		CHARGES—(Weight in pou			Studless					
		Silk Cloth Cartridges.			Common Shell.			Shrapnel Shell.		
					Empty, complete, with Gas-check.					
Guns.	Mark.	Full.	Redu	P.C., or Pistol.						
				oz.	Mark.	lb.	oz.	Mark.	lb.	oz.
17·72-in., 100 tons	I	450 Prism^{1} black or Prism^{2}A	337½ Pri		I	1921	8	I	1995	0
16-in., 80 tons ...	I	450 Prism^{1} brownA	337½ Prism		II	1640		II	1695	13
					IIIR	1585	0			
12·5-in., 38 tons	I	130 P^{2}DR ; 165 Prism^{1} black or Prism^{2}CPH	100 P^{2}CR							

R.M.L. CARRIAGES AND SLIDES (LAND SERVICE).

RDNANCE.	Carriages.		Elevation in Degrees.	Depression in Degrees.	Slides.		Radii of Racers.				Height of Axis of Trunnions above the Ground in Firing Position.		Weight.			
	Material	Nature.			Material	Nature.	Front		Rear.				Carriage.		Slide.	
							ft.	in.	ft.	in.	ft.	in.	tons.	cwt	tns.	ct.
7·72-in., 100 tons	Iron	... ...	11	11	Iron	... ...	—		—		10	6	20	7	25	14¾
-in., 80 tons	,,	... ...	7	2	,,	... ...	—		—		6	5⅝	—		—	
5-in., 38 tons	,,	7-ft. recoil, small port	7	4	,,	7-ft. recoil, small port	10	2	21	2	†4	7½	10	6¾	7	10
		6-ft. recoil, small port	7	4	,,	6-ft. recoil, small port	10	2	20	2	‡5	9½	9	13¾	8	9¼
		7-ft. recoil, casemate	10	5	,,	7-ft. recoil, casemate	10	2	21	2	4	11¼	6	3¼	8	3¾
		6-ft. recoil, casemate or dwarf	10	5	,,	6-ft. recoil, casemate	10	2	29	2	4	11¼	6	2¼	8	2¼
						Dwarf, "C"	5	8	5	8	6	0¼			9	8¼
						6-ft. recoil, casemate, special	10	2	21	2	4	11¼			8	8
						Dwarf, "D"	8	0	3	8	6	0¼			9	4½
						7-ft. parapet, "C," converted casemate, special	5	8	5	8	8	9½			9	19½
						7-ft. parapet, "C," converted dwarf "O"	5	8	5	8	8	9½			—	
		Converted small port	15*	5	,,	"C," converted small port	5	8	5	8	8	10¼	—		—	
in., 35 ons	,,	Dwarf	10	5		Dwarf "C"	5	8	5	8	6	0¼	5	15¼	9	6¾
in., 25 ons in., 25 ons	,, ,,	Casemate or dwarf	15	5	,,	Casemate, to work within length	8	0	18	0	4	11¼	3	7½	5	12
						Dwarf, "A" rear ...	8	0	18	0	6	8			6	19¼
						,, "C," central or side	5	8	5	8	6	3			7	2½
						7-ft. parapet, C ...	5	8	5	8	—				7	2½
4-in., 28 ons	,,	Barbette	15	4½	,,	Barbette	—		12	10⅝	9	1½	6	1	7	8
n., 18 ons	,,	Casemate or dwarf	10	5	,,	Casemate, to work within length: Mark I. ...	8	0	18	0	4	2½	2	11¾	4	17¾
		Casemate, Mark II.	10	5	,,	,, II. ...					4	2½	3	7	5	4
						,, special					4	11½			6	5
						,, converted					4	11½			6	19½
		Casemate or dwarf	10	5	,,	Dwarf, A pivot, rear					6	0	2	11½	6	14¾
						,, C ,, central	5	8	5	8	6	0			7	0½
						,, D ,, ...	9	0	3	0	6	0			7	1
						7-ft. parapet, C, Mark I.	5	8	5	8	8	9½			7	19¼
		Small port	9	4	,,	Small port	8	0	18	0	†4 6¾ ‡5	6¾	6	0	5	6
., 12 ns	,,	Garrison, Mark III.	...	...	,,	7-foot parapet, C, Mark II.	5	8	5	8	8	9½	3	0½	8	12½

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* Not more than 10° to be given when firing full charges.

† Least height.

‡ Greatest height.

R.M.L. CARRIAGES AND SLIDES (LAND SERVICE).—(*Continued*).

ORDNANCE.	Carriages.		Elevation in Degrees.	Depression in Degrees.	Slides.		Radii of Racers.				Height of Axis of Trunnions above the Ground in Firing Position.		Weight.			
	Material	Nature.			Material	Nature.	Front		Rear.				Carriage.		Slide.	
							ft.	in.	ft,	in.	ft.	in.	tons.	cwt	tns.	ct.
9-in., 12 tons	Iron	Casemate or dwarf, Mark I	10	5	Iron	Casemate, to work within length	6	3	16	6	4	1½	2	2¼	3	14¾
						Dwarf, A pivot, rear					5	9			4	17
						Dwarf, C pivot, central	5	5¾	5	5¾	5	9			5	10
						Dwarf, D pivot ...	9	0	2	3¾	5	9			5	7
						7-ft. parapet, C pivot, Mark I	5	5¾	5	5¾	8	6½			6	1
		Converted Naval, single plate	12	9	,,	Converted Naval slide	5	1	13	5	4	1	2	4	3	0
					,,	Casemate, Elswick	5	5½	16	6	4	9·5	—		2	17½
		Garrison, Mark II.	20	12	,,	7-ft. parapet, C pivot, Mark III	5	5¾	5	5¾	8	6½	2	8	8	8¼
						7ft. parapet, C pivot, Mark IV	5	5¾	5	5¾	8	6½	2	8	—	
		High Angle, Mark I.	70	—	—	... ...	4	9	4	9	9	6½	20	16	—	
		High Angle, Mark II.	70	—	—	... ...	5	5¾	5	5¼	8	10¾	—		—	
		High Angle, Mark III.	70	—	—	... ...	4	4	4	4	6	6	16	13½	—	
		Moncrieff	15	5	—	... ...	11	10	6	2	14	0	26	10	14	0
8-in., 9 tons	,,	Converted Naval, single plate	12	9	Iron	Converted Naval slide	—		—		3	9½	1	19½	2	15½
		Elevation	16	9	,,	Elevation	—		—		3	5½	1	19	2	15½
7-in., 7 tons	,,	Casemate or dwarf	20	5	Iron	Casemate	6	3	16	6	4	1½	1	7¾	2	13
						Dwarf, A pivot ...	6	3	16	6	5	8¾			3	17¾
						,, C ,, ...	5	5¾	5	5¾	5	8¾			4	0¾
						,, D ,, ...	9	0	2	3¾	5	8¾			4	0¾
		Moncrieff, Mark I.	15	5	—	—	8	3½	5	8½	10	11¾	92	3½	—	
		,, Mark II.	15	5	—	—	9	10	5	7½	12	3½	22	18	—	
7-in., 6½ tons	,,	Converted Naval, S. plate	13½	7	,,	Dwarf, S.P. carriages, C pivot	—		—		5	8	1	7½	4	0¾
						Dwarf, S.P. carriages, D pivot	—		—		5	8			4	0¾
		Converted Naval, with hydraulic buffer	15	7	,,	Converted slide, 4° slope for hydraulic buffer	5	1	13	6	3	5	1	12	1	19
		Converted Naval, with compressor gear	15	7	,,	Converted slide, 4° slope, with compressor gear					3	4½	1	7½	1	17½
		Iron sliding, medium, No. 7	30	5	,,	Traversing medium, No. 7, 6-ft. parapet	6	1	6	1	7	1	2	14½	3	15½
6·6-in., 70 cwt.	Steel	Siege (H.P.)	12	5	—	—	—		—		8	5½	2	12⅝	—	
80-pr. (con.) 5 tons.	Wood	Sliding medium, No. 21	7§	5	Wood	Traversing medium No. 14, casemate	5	0	16	6	3	6¾	0	15½	1	7

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§ Elevation from bed, with screw removed.

R.M.L. CARRIAGES AND SLIDES (LAND SERVICE).—(Continued).

ORDNANCE.	Carriages.		Elevation in Degrees.	Depression in Degrees.	Slides.			Radii of Racers.		Height of Axis of Trunnions above the Ground in firing position.	Weight.	
	Material	**Nature.**			Material	Nature.		Front	Rear.		Carriage.	Slide.
								ft. in.	ft. in.	ft. in.	tons. cwt	tns. ct.
80-pr. (con.) 5 tons	Wood	Sliding medium, No. 22	18§	5	Wood	Traversing medium, No. 16, dwarf	C	6 1	6 1	5 2	0 15¾	1 17
							D	9 3	3 4¼			
							E	10 8¼	2 2			
							F	12 10	2 2			
						Traversing medium, No. 18, 6-ft. parapet	C	6 1	6 1	7 1		2 13
							D	9 3	3 4¼			
							E	10 8¼	2 2			
							F	12 10	2 2			
64-pr., 64 cwt.	,,	Common, standing	19§	10	—	—		—	—	—	0 8¾	—
	Iron	Sliding medium, No. 9	15	5	Iron	Traversing medium, No. 9, 5-ft. 6-in. parapet.	C	6 1	6 1	6 6	1 7	2 18
							D	9 0	3 4¼			
							E	10 8¼	2 2			
							F	12 10	2 2			
	,,	Sliding medium, No. 8	15	5	,,	Traversing medium, No. 8, 6-ft. parapet	A	5 0	16 6	7 0	1 14¾	3 9¾
							C	6 1	6 1			
							F	10 8¼	2 2			
							E	12 10	2 2			
	,,	Sliding medium, No. 26	15	5	,,	Traversing medium, No. 21, 6-ft. parapet	A	5 0	16 6	7 0	1 14¾	—
							C	6 1	6 1			
							E	10 8¼	2 2			
							F	12 10	2 2			
64-pr., 71 and 58 cwt.	,,	Sliding medium ...	20	5	—	—		—	—	3 5	0 17¼	—
	,,	Sliding medium, No. 10	15	5	Wood	Traversing medium, No. 11, dwarf	C	6 1	6 1	5 1½	1 3	2 4
							D	9 0	3 4¼			
							E	10 8¼	2 2			
							F	12 10	2 2			
						Traversing medium No. 12, casemate		5 0	16 6	4 6½		1 14¾
	Wood	Sliding medium, No. 23	20§	5	,,	Traversing medium, No. 16, dwarf	C	6 1	6 1	5 1	0 12½	1 17
							D	9 3	3 4¼			
							E	10 8¼	2 2			
							F	12 10	2 2			

§ Elevation from bed, with screw removed.

The letters A, B, C, D, E and F refer to the nature of pivot.

R.M.L. CARRIAGES AND SLIDES (LAND SERVICE).—(Continued).

ORDNANCE.	Carriages.		Elevation in Degrees.	Depression in Degrees.	Slides.		Radii of Racers.		Height of Axis of Trunnions above the Ground in Firing Position.	Weight.	
	Material	Nature.			Material	Nature.	Front	Rear.		Carriage.	Slide.
							ft. in.	ft. in.	ft. in.	tons. cwt	tns. ct.
64-pr., 71 & 58 cwt.	Wood	Sliding, medium, No. 23	20§	5	Wood	Traversing medium, No. 18, 6ft. parapet, C D E F	6 1 9 3 10 8¼ 12 10	6 1 3 4 2 2¼ 2 2	7 0	0 12¼	2 13
64-pr., 71 cwt.	,,	Common, standing	17§	6	—	—	—	—	3 4½	0 8¾	—
	Iron	Sliding, medium, No. 11	15	8	Wood	Traversing medium, No. 13, casemate	5 0	14 0	4 6	1 4½	1 10¾
	,,	Sliding, medium, No. 12	12	8½	,,	Traversing medium, No. 19, 2-ft. 7-in. parapet	5 0	16 6	3 10	1 3	1 13¼
	,,	Sliding, medium, No. 10	15	5	,,	Traversing medium, No. 20, 6-ft. parapet	5 0	16 6	7 0	1 3	3 3
64-pr., 58 cwt.	Wood	Common, standing	17§	6	—	—	—	—	3 4½	0 14¾	—
	,,	Depression	—	30	—	—	—	—	3 4½	0 16	—
	Iron	,, ...	—	32	—	—	—	—	3 7	1 9½	—
	Wood	,, No. 25	10§	6	Wood	Traversing medium, No. 14, casemate	5 0	16 6	3 6½	0 11	1 7
	Iron	,, No. 13	—	—	,,	Traversing medium, No. 11 or 12 (*see* page 347)	—	—	—	1 2½	—
	,,	Moncrieff, with platform	10½	5	—	... ... C D	6 10 8 11	6 10 4 8½	10 5	11 9	—
40-pr., 34 & 35 cwt.	,,	Sliding, medium, No. 14	10	8	Iron	Traversing medium, No. 10, casemate	5 0	14 0	3 6	0 11½	1 4½ Limber
		Siege, Mark I. ...	35	5	—	—	—	—	4 5	1 7	0 13¼
		,, Mark II. ...	35	5	—	—	—	—	4 5	1 12½	0 13¼
		Top, overbank ...	35	5	—	—	—	—	6 3	*0 10½	—
25-pr., 18 cwt.	,,	Field	45	5	—	—	—	—	3 10	0 15	0 11¼
		Siege, top, overbank	35	5	—	—	—	—	6 0	*0 8½	—
16-pr., 12 cwt.	,,	Mark I., strengthened	22½	12½	—	—	—	—	3 7½	0 13½	0 11¼
		Mark II....	17	15	—	—	—	—	3 7½	0 13	0 11
15-pr. jointed, 422lbs	Steel	Mountain, Mark I.	25	10	—	—	—	—	2 1½	0 3¾	—
13-pr, 8 cwt.	,,	Field	16	5	—	—	—	—	3 7	0 12	0 12
9-pr., 8 & 6 cwt.	Iron	Mark I., strengthened	21	4		—	—	—	3 6½	0 12⅝	0 11⅝
		Mark II....	22	6	—	—	—	—	3 6½	0 11⅝	0 11⅜
2·5-in., jointed 400 lbs.	Steel	Mountain, Mark II	25	15	—	—	—	—	2 1¾	0 4¾	—
	,,	Field, Mark I. ...	27½	12½	—	—	—	—	2 4¾	0 4¾	0 5
7-pr., 200 lbs.	Iron	Field	35	10	—	—	—	—	3 8¾	0 9½	0 9¾
	,,	Mountain	33	8	—	—	—	—	2 1¾	0 3½	0 3⅝
	,,	Bed	22	5	—	—	—	—	1 2¼	0 2	—

* Weight of top carriage only.

§ Elevation from bed, with screw removed.

The letters C D, E and F refer to the nature of pivot.

R.M.L. CARRIAGES AND SLIDES (LAND SERVICE).—(Continued).

Ordnance.	**Carriages.**		**Elevation in Degrees.**	**Depression in Degrees.**	**Slides.**		**Radii of Racers.**		**Height of Axis of Trunnions above the Ground in Firing Position.**	**Weight.**	
	Material	**Nature.**			**Material**	**Nature.**	**Front**	**Rear.**		**Carriage.**	**Slide.**
							ft. in.	ft. in.	ft. in.	tons. cwt	tns. ct.
7-pr. 150 lbs.	Iron	Bed	45	5	—	—	—	—	1 10	0 2¾	—
	Steel	Gold Coast	20	5	—	—	—	—	2 0	0 3⅛	—
	Wood	,, ...	20	5	—	—	—	—	2 0	0 2½	—
Howitzers.											
8-in., 70 cwt.	Iron	Siege, 70-cwt. ...	35	5	—	—	—	—	4 5	2 4	†0 12⅒
	,,	Siege, 46-cwt., converted	—	—	—	—	—	—	—	—	—
8-in., 46 cwt.	,,	Siege 46-cwt. ...	30	—	—	—	—	—	4 8½	2 11½	†0 12⅒
	,,	Bed	45	—	—	—	—	—	2 6	1 13	—
6·6-in., 36 cwt.	,,	Siege	35	5	—	—	—	—	4 5	1 18	†0 12⅒
	Steel	Bed	45	—	—	—	—	—	3 0½	1 11	—
6·3-in., 18 cwt.	Iron	Siege	40	5	—	—	—	—	4 5	1 17½	†0 12⅒
	Steel	Bed	70	—	—	—	—	—	3 0½	1 11¼	—
4-in. jointed, 600lbs	,,	Mountain	36	7	—	—	—	—	2 2⅗	0 5⅓	—

† For siege train, 12¼ cwt.

3.—QUICK-FIRING AND

QUICK-FIRING

Ordnance, Quick-Firing						Bore.		Ballistic Effects.			
										Penetration of steel Plate in Inches.	
Nature.	Mark.	Weight.	Material.	Service.	Total Length in Inches.	Calibre in Inches.	Length in Inches.	Muzzle Velocity in foot-seconds.	Muzzle Energy in foot-tons.	At Muzzle.	At 1,000 yards.
6-inch	I, III II	7 tons ,,	Steel Steel and wire	N C	249·25	6·0	240	*a* 1882 *b* 2200	2458 3356	9·4 11·1	8·0 9·4
4·7-inch	I II, III IV, *c*	41 cwt. ,, 42 cwt.	Steel ,, Steel and wire	N C N	194·1	4·724	189	*a* 1786 *b* 2188	995 1494	6·7 8·4	5·4 7·7
4-inch	I	26 cwt.	Steel and wire	N	165·25	4·0	160	*b* 2456	1046	7·6	5·4
12-pr. 12cwt. ..	I	12 cwt.	Steel	C	123·6	3·0	120	*b* 2210	423·4	5·6	4·0
12-pr. 8cwt. ...	I	8 cwt.	Steel	N	87·6	3·0	84	*b* 1607	223·8	3·9	2·8
Hotchkiss, 6-pr.	I II	8 cwt. ,,	Steel ,,	C L	97·63	2·244	89·76	1818	136·9	3·2	2·0
Nordenfelt, 6-pr.	I II III	6 cwt. ,, ,,	Steel ,, ,,	N C L	104·4	2·24	95				
Hotchkiss, 3-pr.	I II	5 cwt. ,,	Steel ,,	C L	80·63	1·85	74	1873	80·2	2·4	1·5
Nordenfelt, 3-pr....	I	4 cwt.	Steel	L	91·5	1·85	84	1920	84·4	2·5	1·5

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a. With powder charge. *b*. With cordite charge at 80 degrees F.

c. Some 4·7 inch Mark III, all Mark IV, and all guns of future manufacture will have the letter A added to their nomenclature, indicating that they are fitted with the tappet arrangement mentioned in *List of Changes*, § 7119.

MACHINE GUNS.

GUNS.

Rifling.						Fuzes.		Ordnance, Q.F.	
System.	Twist.	Length in Inches.	Grooves.			Time.	Percussion.	Nature.	Mark.
			Number.	Width in Inches.	Depth in Inches.				
Polygroove (hook section)	II. from 1 in 60 at breech, to 1 in 30 at muzzle.	214·7	24	0·6	0·05	—	—	6-inch	I, III II
Polygroove (Elswick)	I. from 1 in 100 at breech, to 1 in 34·352 at 6·65 inches from the muzzle. Remainder U. 1 in 34·352	171	22	0·5	0·04	Middle sensitive	Base percussion, Armstrong III.	4·7-inch ...	I II, III IV
Polygroove (plain section)	Straight for 21·536 inches from breech, then increasing from 0 to 1 in 30 at 1·92 inches from muzzle. Remainder U. 1 in 30	143·456	24	·35 *d* ·315*e*	·06*d* ·04 *e*	—	—	4-inch	I
Polygroove (Elswick)	I. from 1 in 120 at breech, to 1 in 28 at muzzle	103·315	16	0·4	0·04	—	Hotchkiss, base	12-pr. 12cwt. ...	I
Polygroove (Elswick)	I. from 1 in 60 at breech, to 1 in 28 at muzzle	74·81	16	0·4	0·04	—	—	12-pr. 8cwt. ...	I
Polygroove (plain section)	I. from 1 in 180 at breech, to 1 in 29·89 at 9·98 inches from the muzzle. Remainder U. 1 in 29·89	76·91	24	0·22	0·012	—	Base percussion, Hotchkiss or Nordenfelt	Hotchkiss, 6-pr.	I II
Polygroove (plain section)	I. from 1 in 180 at breech, to 1 in 29·89 at 14·98 inches from the muzzle. Remainder U. 1 in 29·89	81·91	24	0·22	0·012	—		Nordenfelt, 6-pr.	I II III
Polygroove (plain section)	U. 1 in 25	58·35	20	0·23	0·015	—		Hotchkiss, 3-pr.	I II
Polygroove (plain section)	I. from 1 in 100 at breech, to 1 in 30 at 9·7 inches from the muzzle. Remainder U. 1 in 30	68·217	20	0·194	0·012	—		Nordenfelt, 3-pr.	I

d. At the breech end.
At the muzzle end.

Machine Guns. — Nature.	Calibre.	Number of Barrels.	Mark and Letters.	Service.	Weight of Gun complete with Distributor and Feed Guide or Cartridge Feeder, but without Mounting or Shield.	Total Length.	Sighted up to	Length of Barrels.	Rifling.			
									System.	Pitch.	Length.	Number of Grooves.
	ins.				lbs	ins.	yds.			1 in	in.	
Nordenfelt	1·0	2	I	N	180	52·75	3000	35·48	Henry	35	31·39	11
,, ...	1·0	4	I	N	426	57·0	3000	35·48	,,	60	31·39	11
,, ...	1·0	4	II	N	440	57·0	3000	35·48	,,	35	31·39	11
,, ...	1·0	4	III	N	447	57·0	3000	35·48	,,	35	31·39	11
,, ...	0·45	3	I M.H.	L	103	41·5	1800	28·5	,,	22	25·6	7
,, ...	0·45	5	I G.G.	N*	160	46·0	2000	28·5	,,	22	25·6	7
,, ...	0·45	5	II G.G.	N*	143	42·25	2000	28·5	,,	22	25·6	7
Gardner	0·45	1	I G.G.	N	76	47·0	2000	30·0	,,	22	27·1	7
,, ...	0·45	1	M.H.	L	59	47·0	2000	30·0	,,	22	27·1	7
,, ...	0·45	2	I G.G.	N*	120	47·0	2000	30·0	,,	22	27·1	7
,, ...	0·45	2	I M.H.	L	92	47·0	2000	30·0	,,	22	27·1	7
,, ...	0·45	5	I G.G.	N*	268	58·5	2000	33·0	,,	22	30·1	7
,, ...	0·4	2	I E.M.	L	88	45·5	2000	28·5	Enfield	15	25·5	7
,, converted from 0·4-in. ...	0·45	2	M.H.	L	88	45·5	2000	28·5	Henry	22	25·5	7
Gatling	0·65	10	—	N	787	66·5	2000	33·0	,,	30	28·1	7
,, ...	0·45	10	I G.G.	N*	402	59·0	2000	31·95	,,	22	29·0	7
,, "Accles' Feed"	0·45	10	I G.G.	N	266	51·0	2000	32·0	,,	22	29·1	7
Maxim	0·45	1	I G.G.	N	60	43·75	2000	29·2	,,	22	26·31	7
,, ...	0·45	1	I M.H.	L	60	43·5	2000	29·2	,,	22	26·75	7
,, ...	0·303	1	I	L	60	42·375	2500	28·375	Metford a	10	25·625	7

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a These guns in future will be rifled on a different system, having 5 deep grooves.
* The use of these guns in L. S. is quite exceptional.

GUNS.

Weight of Hopper, Drum, Cartridgeholder, Feed-box or Belt.		Number of Cartridges in Hopper, Drum, Cartridgeholder, Feed-box, or Belt.	NATURE OF AMMUNITION.	Powder Charge.	Projectile.	Penetration.	NATURE OF GUN.
Empty.	Filled.						
lb. oz.	lb. oz.			grains.			
13 0	27 0	20	Solid case, steel projectile.	625 M.G.[1]	7·25 oz.	Perforates ¾" steel plate at 200 yards.	Nordenfelt, 1·0-in., 2-bl., Mark I.
20 0	48 0	40	,, ,,	625 ,,	7·25 oz.	,, ,,	Do. do. 4-bl., Mk. I.
20 0	48 0	40	,, ,,	625 ,,	7·25 oz.	,, ,,	Do. do. do., Mk. II.
20 0	48 0	40	,, ,,	625 ,,	7·25 oz.	,, ,,	Do. do. do. Mk. III.
0 7½	3 12	27	M.H., solid case	85 R.F.G.[2]	480 gr.	Same as M.H. rifle, which perforates ⅛-inch wrought-iron plate at 600 yards, $\frac{3}{16}$-inch plate at 400 yards, and ¼-inch at 100 yards.	Do., ·45-in., 3-bl., M.H. Mk. I.
5 2	10 14	50	Gardner-Gatling	85 ,, *d*	480 gr.		Do. do., 5-bl., Mk. I.
5 2	10 14	50	,, ,,	85 ,, *d*	480 gr.		Do. do. do., Mk. II.
0 7	2 12	20	,, ,,	85 ,, *d*	490 gr.		Gardner, ·45-in. 1-bl., G.G., Mk. I.
0 7	2 14½	20	M.H., solid case	85 ,,	480 gr.		Do. do. do., M.H., Mk. I.
0 7	2 12	20	Gardner-Gatling	85 ,, *d*	480 gr.		Do. do., 2-bl., G.G., Mk. I.
0 7	2 14½	20	M.H., solid case	85 ,,	480 gr.		Do. do. do., M.H., Mk. I.
3 5	9 0	50	Gardner-Gatling	85 ,, *d*	480 gr.		Do. do., 5-bl., G.G., Mk. I.
0 7	2 9½	20	·4-inch, solid case	85 ,,	384 gr.	—	Do., ·4-in., 2-bl.
0 7	2 14½	20	M.H., solid case	85 ,,	480 gr.	—	Do., ·45-in., M.H., converted.
28 8	46 5	50	·65-inch rolled case	270 ,,	1422 gr.	—	Gatling, ·65-in., Mk. I.
29 0	56 12	240	Gardner-Gatling	85 ,, *d*	480 gr.	Same as M.H. rifle	Do., ·45-in., G.G., Mk. I.
17 8	29 1	100	,, ,,	85 ,, *d*	480 gr.	,, ,,	Do. do., G.G., (Accles'), Mk. I.
4 8 2 0	48 12 18 8	334 140	,, ,,	85 ,, *d*	480 gr.	,, ,,	Maxim, ·45-in., G.G., Mk. I.
1 8 2 0	20 4 34 0	150 *b* 250 *c*	M.H., solid case	85 ,,	480 gr.	,, ,,	Do. do., M.H., Mk. I.
2 6	17 0	250	Solid case, stamped "C"	31 (cordite, size 3¾)	215 gr.	—	Do., 0·303-in., Mk. I.

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b. For field carriages (infantry and cavalry).

c. For parapet carriages, pack transport carriages, and cone mountings.

. A cordite carriage has been approved, § 7663, for use in all 0·45 machine guns with G.G. chambers

ORDNANCE, Q.F.		PROJECTILES AND THEIR BURSTING CHARGES.											
											Shot.		
Nature.	Mark.	Mark.	Armour-piercing Shell, Weight filled & fuzed.	Bursting Charge.	Mark.	Common Shell, Weight filled and fuzed.	Bursting Charge.	Mark.	Shrapnel Shell, Weight filled and fuzed.	Bursting Charge.	Mark.	Armour piercing.	Case.
			lb oz	lb oz dr		lb oz	lb oz dr		lb oz	lb oz dr		lb oz	lb oz
6-inch	I, II, III	—	—	—	V*a*	100 0	7 6 0	II*a*	—	0 7 0	I*c*	100 0	—
					VI*b*	100 0	9 13 0	IV*c*	100 0	0 10 8	—	—	
								V*b*	—	0 10 8	—	—	
4·7-inch ...	I to IV	III*c*	45 0	1 15 0	II*a*	45 0	2 15 8		45 0	0 5 0	—	—	—
					III*b*	45 0	4 4 0	—	—	—			
4-inch	I	I*c*	25 0	0 14 0	I*c*	25 0	—	—	25 0	—	—	—	—
12-pr., 12 cwt.	I	I*c*	12 8	0 9 8	I*b*	12 8	1 8 0	—	—	—	—	—	—
12-pr., 8 cwt.	I	—	—	—	I*b*	12 8	1 8 0	—	—	—	—	—	—
6-pr. Hotchkiss	I, II	—	—	—	III*c*	6 0	0 4 0	—	—	—	—	—	—
6-pr. Nordenfelt	I, II, III				II*a*	6 0	0 3 0	—	—	—	—	—	—
. Hotchkiss	I, II	—	—	—	II*c*	3 $4\frac{12\cdot75}{16}$	0 2 0	—	—	—	—	—	—
3-pr. Nordenfelt	I				II*a*	3 $4\frac{5\cdot5}{16}$	0 1 8	—	—	—	—	—	—

a. Iron *b.* Cast Steel. *c.* Forged Steel.

GUNS.

Description of Ammunition.	Charges.						Ordnance, Q.F.	
	Full.		Reduced.		Saluting.		Nature.	Mark.
	Weight.	Nature.	Weight.	Nature.	Weight.	Nature.		
	lb oz dr		lb oz dr		lb oz dr			
Charge in brass case, with electric primer attached. Projectile separate. Adapter for percussion firing can be substituted for electric primer if necessary.	29 12 0	E.X.E.	14 0 0	P.^{2}[e]	—	—	6-inch	I, II, III
	13 4 0	Cordite, size 30/14	—	—	—	—	—	—
	12 0 0	S.P.	8 0 0	S.P.[f]	3 0 0	Blank, L.G.	4·7-inch ...	I to IV
	5 7 0	Cordite, size 20/14	8 8 0	P.^{2}[e]	—	—	—	—
	3 12 0	Cordite, size 15/14	2 2 8	Cordite 8/12[g]	—	—	4-inch	—
	1 9 8	Cordite, size 10/14	—	—	—	—	12-pr., 12 cwt.	—
	18 8	Cordite, size 10/11					12-pr., 8 cwt.	—
Charge in brass case, with percussion cap in base, and projectile attached as in Small-arm Ammunition.	1 15 0	Q.F.^{1}	—	—	15 0	Blank, L.G.	Hotchkiss, 6-pr.	I, II
	7 12 4	Cordite, size 5/11 R.F.G.^{2}	—	—	—	—	Nordenfelt, 6-pr.	I, II, III
	1 8 0	Q.F.^{1}	—	—	15 0	Blank, L.G.	Hotchkiss, 3-pr.	I, II
	6 6 4	Cordite, size 5/11 R.F.G.^{2}	—	—	—	—	Nordenfelt, 3-pr.	I

[e] For practice from Gunnery Ships, when P^2 is available.
[f] For practice from Gunnery Ships, and for Land Service when specially ordered.
[g] For use in Gunnery Ships only.

MOUNTINGS FOR QUICK-FIRING GUNS.

Ordnance, Q.F.		Nature of Mounting.	Mark.	Service	Elevation in Degrees.	Depression in Degrees.	Width.	Length.		Height of axis of trunnions.		Weight.	
								Carriage.	Gun and Carriage.	From Pivot Plate.	From Deck or Gun Floor.	Mounting or Carriage without Shield.	Limber without Stores.
							ins.	ins.	ins.	ins.	ins.	ct. qr.	ct. qr.
nch		Central pivot*	I	N	20	7	80	83	254	37·65	44	118 3	—
		Pedestal U.D.	II	N	—	—	—	—	—	—	—	91 2†	—
-inch ...	II, III	Central pivot	I	L	20	10	53	—	—	32·625	45·6	55 2	—
	I to IV	Upper deck	I, II	N	20	7	60	82	208	32·625	48	47 0	—
		Between deck	I, II	N	15	7	50	75	202	31·5	43	54 1½	—
		Pedestal...	III	N	20	7	69	72	207	38	45	50 2¼	—
		,, ...	IV	N	—	—	—	—	—	—	—	44 2	—
nch		,, ...	IV	N	20	10	71	102	177	40	40	34 1	—
-pr., 12cwt. ...		,, ...	I	L	20	5‡‡	66	51	128	—	43·5	18 2¼	—
		Ship	II	N	—	—	—	—	—	—	—	—	—
-pr., 8cwt.		General	I	N	20	15	72	81	120	35	—	1¾	—
		Field carriage	—	N	8	—	55	82	137	—	32·5	14 1‡	—
r. Hotchkiss	I	Recoil§	I	N	25	15	26	57‖	102	15·975	—	5 3	—
	I	Frame stand	I	C	18	30	41·5	58·25	108·9	—	43	11 1¾	—
	II	Recoil embrasure ...	I	L	20	20	—	—	—	22·55¶	—	8 2¼	—
		Recoil cone	I	L	20	20	—	—	—	—	43·435	10 3½	—
r. Nordenfelt	I	Recoil	I	N	25	18	56·8	44·5	104	—	43·43	15 2	—
	I, II	Frame stand...	I, II	N	18	25	—	—	—	—	—	13 1½	—
	III	Recoil embrasure ...	I	L	20	20	—	—	—	22·55¶	—	9 0	—
		Recoil cone	I	L	20	20	—	—	—	—	43·435	10 3	—
r., Hotchkiss	I	Elastic frame stand ...	I	C	25	35	—	—	—	—	48	7 0¾	—
	I	Recoil	I	N	25	9	23	26‖	104	—	43	5 3	—
	II	Travelling carriage ...	I	L	12	5½	60	97	139·5	—	41·5	11 3	10 2¾
	II	,, ,, ...	II	L	12	5½	60	97	139·5	—	41·5	11 3	9 2
r., Nordenfelt	I	, ,, ...	I	L	15	5½	60	97	139·5	—	41·5	11 3	10 2¾
	II	,, ,, ...	II	L	15	5½	60	97	139·5	—	41·5	11 3	9 2

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* The B.D. mounting is 6 inches less in height of axis than the U.D., and gives 15 degrees of elevation only.
† The B.D. mounting weighs only 90 cwt.
‡ Weight of carriage and limber.
§ Fitted with trunnion bearing adapters, and can be used for Hotchkiss 6-pr., or Nordenfelt I. and II.
‖ Without shoulder piece.
¶ Above sill of embrasure.
‡‡ The shield is made to allow of 5 degrees depression only, and must be cut locally where 15 degrees of depression is required.